19th World Congress of Soil Science

Symposium 3.2.1
Highland agriculture and conservation of soil and water

Soil Solutions for a Changing World,

Brisbane, Australia

1 – 6 August 2010

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An assessment of the data resolution required to run the PESERA soil erosion model at a catchment scale in a high latitude agricultural catchment

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Abstract

The aim of this study is to evaluate the PESERA soil erosion model as a tool for predicting soil erosion at a catchment scale in a high latitude agricultural catchment in eastern Scotland. We investigate the importance of the resolution of soil and terrain data and the sensitivity of the model to rainfall inputs and therefore it's potential to be used as a tool to model the changing risk of erosion posed by changes in rainfall distribution. We show that the model does have the potential to be used as a land use planning tool in an attempt to minimise sediment loss and preserve water quality. We also show that the model has the potential to be used both as a screening tool due to its relatively limited data requirements and at a finer resolution where more detailed data are available, making it a powerful tool for soil erosion research.

Key Words

Soil erosion, modelling, PESERA, water quality, land allocation.

Introduction

The impact of soil erosion on water quality is well known and affects both aquatic ecosystems and the quality of potable water. Scotland is famed for its clean, clear water, which is associated with high quality luxury exports such as Scotch whisky; however, the cultivation of barley required to make whisky can compromise this image. In high latitude climates, cereals such as barley are spring/summer crops, but early rainfall before crop cover is established can lead to locally severe erosion. As well as increasing river turbidity, the sediment also contains phosphorus, which can lead to eutrophication in the relatively nutrient-poor aquatic systems.

Soil erosion risk models are useful to explore land allocation strategies including a shift to winter cereals within catchments in order to minimise erosion and reduce pollution in aquatic systems. Here we present some output from the freely available Pan-European Soil Erosion Risk Assessment (PESERA) model.

The PESERA model is a soil erosion model that has successfully been run at European (Kirkby *et al. 200*8) and national scales (Lilly *et al.* 2009) on a 1 km grid. The dominant processes represented in the model are runoff generation based on a storage threshold model and sediment transport based on runoff, soil erodibility, and topographic potential (Kirkby *et al.* 2008).

PESERA has been tested at plot and catchment scales in Spain (de Vente *et al.* 2009) and Greece (Tsara *et al.* 2005) and at a plot scale in The Netherlands and Italy (Licciardello *et al.* 2009). In general, it has been found to underestimate soil erosion at these scales (de Vente *et al.* 2009, Tsara *et al.* 2005, Licciardello *et al.* 2009). Reasons that have been suggested for this are that the model does not account for individual high impact events (Licciardello *et al.* 2009), gully or channel erosion (de Vente *et al.* 2008). However it is suggested that improvements can be made to the model predictions using higher resolution data than was available for these studies (de Vente *et al.* 2009, Kirkby *et el.* 2008).

Methods

Model

We explore the use of PESERA model as a tool for assessing relative erosion risk in a catchment in Scotland. In particular we consider:

(1) The use of the model with varying resolutions of soil, terrain and land use data
(2) The ability of the model, given high resolution data, to reflect changes in land use
(3) The ability of the model to respond to changes in rainfall that reflect individual years compared to the 30 year average (1971 – 2000)

Study area and soils

The Lunan water catchment (Figure 1) is a 140 km^2 catchment in the east of Scotland (Figure 1), which is under intensive arable agriculture and subject to multiple pollution pressures. These are being extensively studied as part of a monitored priority catchment partnership involving research and environment protection agency staff. The dominant arable crop is spring cereal, then winter cereals and spring sown root crops, predominantly potatoes.

The soils in the catchment are Brown Earths (Cambisols), Humus Iron Podzols (Podzols), Noncalcareous gleys (Planosols) and mineral alluvial soils (Fluviosls) (Scottish and FAO soil taxonomy; Soil Survey of Scotland Staff 1984; FAO 1990) (Table 1).

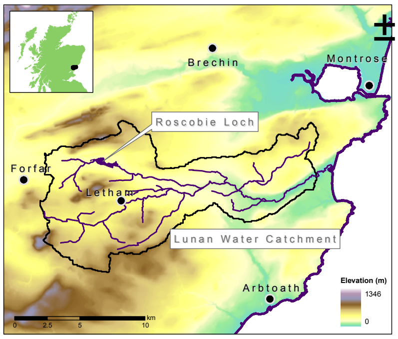

Figure 1. The Lunan Water catchment in north-east Scotland. Based on Ordnance Survey Landform PROFILE ® data. © Crown copyright. All rights reserved. MLURI 100019294 (2009)

Table 1. Soils in the Lunan Water catchment

Series	Cover (km^2)	Major soil sub-group	Drainage	Parent Material
Balrownie	39	Brown earths	Imperfectly drained	Water sorted material generally < 60 cm overlying the above till
Forfar	22.4	Humus Iron podzol	Imperfectly drained	Water sorted material generally > 60 cm overlying till derived from O.R.S. sediments
Aldbar	18.3	Humus Iron podzol	Freely drained	Till derived from Lower O.R.S. sediments mainly sandstone
Corby	14.1	Humus Iron podzol	Freely drained	Water sorted and morainic gravel
Garvock	11.9	Brown earths	Freely drained	Till derived from Lower O.R.S. lava and sediments
Vinny	9.5	Humus Iron podzol	Freely drained	Water sorted material generally > 60 cm overlying till derived from O.R.S. sediments
Undiferentiated Alluvium	8.8	Mineral alluvial soil	Poorly drained	Riverine alluvium
Mountboy	4.6	Noncalcareous gley	Imperfectly drained	Till derived from Lower O.R.S. lava and sediments
Boyndie	2.2	Humus Iron podzol	Freely drained	Fluvioglacial sand

Data

The data available to run the model are:

- 1km European scale Digital Terrain Model (DTM)
- British Ordnance survey PROFILE® (the UK mapping agency) 10 m DTM
- 1:25,000 scale soil series maps
- 1km Grid of the dominant soil series in each grid square
- Predicted soil hydrological information for each of the soil series derived from pedotransfer functions derived from British soils
- Modelled crop rotations for individual fields based on Scottish Integrated Administration and Control System (SIACS) data

Results and Discussion

Soils and terrain inputs

When the resolution of soils data was combined with different resolutions of DTM (Figure 2) it was found that increasing the resolution of the soils data, from the dominant soil series in a 1km grid cell to the soils represented on the 1:25,000 scale map of the catchment (Figures 2b, d and f), highlighted areas close to water courses that are highly susceptible to erosion.

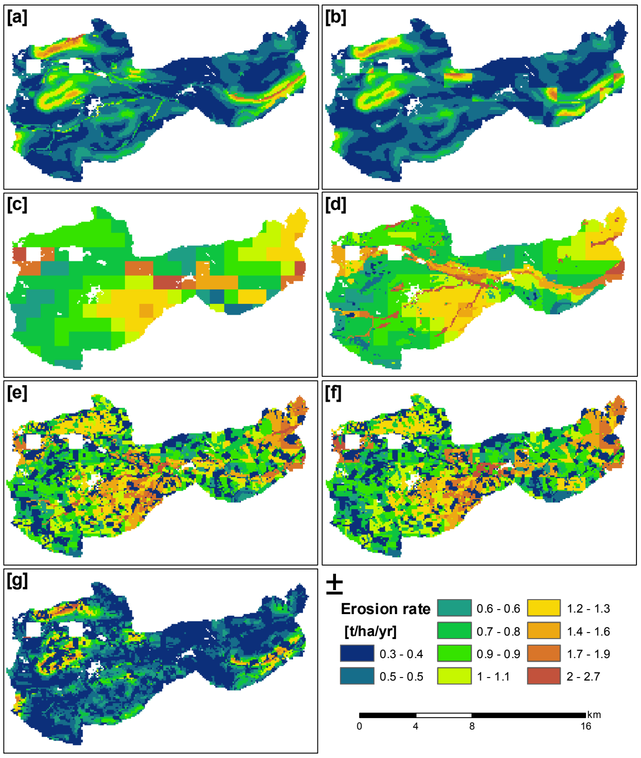

Figure 2. (a) 1:25k soils and OS 100 m DTM, (b) 1 km soils and OS 100 m DTM (c)1km soils and 1 km EU DTM (d) 1:25k soils and 1km EU DTM with SIACS Crops (e) 1 km soils and 1km EU DTM with SIACS Crops (f) 1:25k soils and OS 100 m DTM with SIACS Crops

However ensuring that the terrain input is accurate representation of the terrain in the catchment is vitally important when running the PESERA at a catchment scale. Here we show that the areas with the steepest slope in the west of the catchment, and modeled to have the greatest erosion using a high resolution DTM are not the same areas of the catchment that are modeled to have the highest erosion rates when using the 1 km DTM. Further investigation will look at the link between the input terrain parameter and how this represents the average slope in the catchment.

Using realistic cropping patterns for individual fields based on SIACS data modifies the erosion pattern in the catchment, compared to that based on soils, climate and terrain alone. This suggests that the model can be used as a land allocation planning tool within catchments (Figures 2e, f and g).

Further investigation into the application of the model as a planning tool to minimize soil erosion in a catchment will attempt to integrate the PESERA model outputs with spatially targeted cropping systems. Further investigation, by modeling the whole catchment under one crop, showed that the model was sensitive to the soil texture parameter and that coarse textured soils respond minimally or positively to a change in crops from winter to spring sown, where as medium textured soils respond negatively with increasing erosion rates of up to 30%. Further investigation is currently been undertaken to investigate refining the texture-based erodibility parameters to parameters that are based on the soil's aggregate stability.

Rainfall inputs

Rainfall inputs were changed from the 30 year average (1971-2000) to the values for the individual years 1984 and 1995 to further investigate into the model's sensitivity to changes in rainfall intensity and annual rainfall patterns. The rainfall pattern in 1984 has rainfall peaks in January, March and November, when soil moisture deficits are at their least whereas the 1971 to 2000 average invariably has a much more consistent pattern across months. The results show that there are significant changes (between 45 and 120%) in modelled soil erosion when rainfall inputs are changed from the average to the 1984 values (Figure 3). However when the rainfall pattern for 1995 are used, the erosion is consistently decreased (by a maximum of 30%) compared to the 1971 -2000 average rainfall (Figure 3). The 1995 rainfall pattern is such that a large soils moisture deficit occurs throughout the growing season. These changes occur and appear to be reflecting the rainfall patterns as there is a much smaller percentage change in the annual totals (Average, 770 mm, 1984: 919 mm and 1995 866 mm).

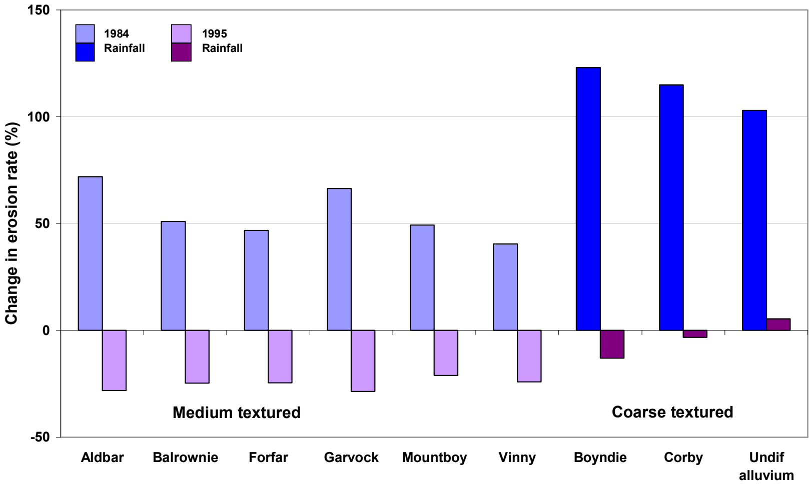

Figure 3. Percentage change in erosion rates using 1984 and 1995 rainfall compared to the 1971-2000 average

Conclusion

This study has shown that the PESERA model can be used as a broad scale screening tool for soil erosion as it has minimal data requirements. However we show that with higher resolution data inputs it has the potential to be used as a land use planning tool at a catchment scale. In addition, the model is sensitive to changes in rainfall patterns and has the potential to be used to assess the risk of soil erosion under future climate scenarios, where rainfall is predicted to change.

We also show that the model is very sensitive to the terrain parameter and that misrepresentation of this can give a skewed representation of erosion within a catchment. In addition increasing the resolution of soils data shows important improvements in the soil erosion predictions.

Future work will seek to further examine the potential of the model to be used as a land use planning tool to minimise soil erosion and to link the soil erosion estimates to measured suspended sediments as a partial validation exercise. We also hope to improve the representation of erodibility within the model based on measurements of aggregate stability.

Acknowledgements

This work was funded by the Rural Environment Research and Analysis Directorate of the Scottish Government (RERAD)

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Application of ^{137}Cs accumulation in soil in predicting soil erosion from different land uses in Haui Raen-Klongpid watershed, Eastern Thailand

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Abstract

^{137}Cs accumulation in soil profiles from 0-30 cm depth were measured in different land uses (forest, banana orchard ,cashew orchard and pine apple plantation) in the Huai Raeng-Klongpid Watershed, Trat Province,Thailand. Soil samples from different land uses were selected at 3 sampling points at 5 cm intervals to 30 cm deep. The ^{137}Cs activity in the soil samples was determined by gamma spectrometry using a High Purity Germanium (HPGe) detector. The ^{137}Cs accumulation in soil in the forest, banana orchard, and cashew orchard and pine apple plantation were 16.4, 14.8, 12.3 and 11.2 Bq/kg, respectively. The results from this study implied that ^{137}Cs accumulation for different land uses is related to soil erosion. Therefore, ^{137}Cs technique could be used as a tool for soil erosion evaluation in Thailand.

Key Words

Caesium-137 (^{137}Cs), land use, soil erosion.

Introduction

^{137}Cs is a fallout product from the atmospheric testing of nuclear weapons carried out between 1945-1963. On reaching the earth's surface, ^{137}Cs is in most environments strongly and rapidly adsorbed by fine-grained particulate matter (Bachhuber *et al.* 1982) and its subsequent movement occurs in association with soil and sediment particles in response to accumulation, erosion, transport and deposition processes. The overall objective was a preliminary study of ^{137}Cs accumulation measurement in a small watershed, Huai Raeng – Klongpid, located in the eastern part of Thailand in Trat Province, with an area of 443 km^2 (Figure 1). This area is used for different agroforestry models of land development systems and also acts as a core demonstration unit at the agroforestry research station of Thailand Institute of Scientific and Technological Research (TISTR) on the use of the ^{137}Cs accumulation method and its comparison for basic information as a data base for further study of soil loss from erosion plots. The specific aim was to gather a reliable set of data on the erosion rates in conditions representing the undulating region of Thailand.

Methods

Study site

Huai Raeng – Klongpid watershed is located in Trat Province in eastern Thailand, which is 443 km^2 and is located in the monsoon region. The mean annual rainfall was 4,737 mm and the mean temperature in January was about 38.2°C.

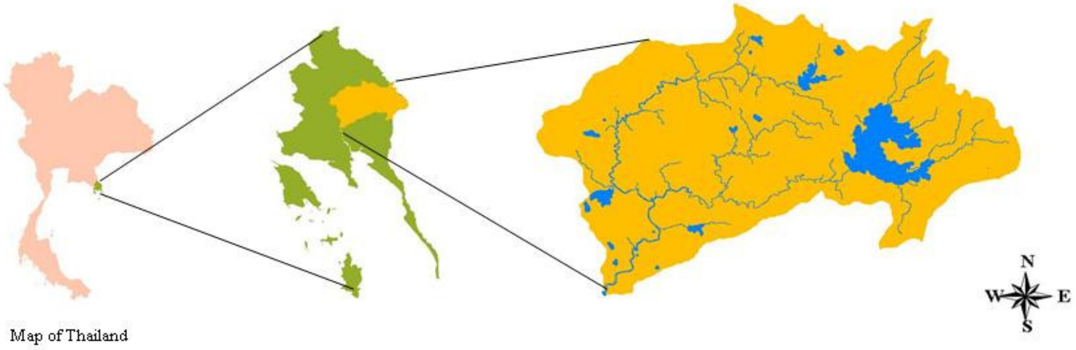

Figure 1. Huai Raeng - Klongpid Watershed study site.

The study area was divided by different slopes: the upland area land use was forest, the central and lowland area were in agriculture cropped to orchards, rubber, pineapple plantations, rice, etc. Some parts of the lowland area also contained a small reservoir and an urban area. A topographic survey was done at the study site, about 72 soil samples for ^{137}Cs analyses were collected from different land uses (forest-3 sampling points, banana orchard-3 sampling points, cashew orchard-3 sampling points and pineapple plantation-3 sampling points). At each sampling point, 6 samples were taken at 5 cm intervals to 30 cm depth profile. Soil samples were dried at 60°C for 48 h, weighed and was passed through a 2 mm screen. Material (rocks, etc.) greater than 2 mm were discarded. The ^{137}Cs activity in soil samples was determined by gamma spectrometry with a High Purity Germanium (HPGe) detector. Calculated ^{137}Cs activity in soil samples is in unit Bq/kg.

Results

The relationship between ^{137}Cs (Bq/kg) accumulation in the profiles and different land uses are given in Table 1 and Figure 2 shows ^{137}Cs accumulation associated with different land uses in the Klongpid- Klonglod Watershed, Trat Province, Thailand.

Table 1. Relationship between ^{137}Cs (Bq/kg) accumulation and different land use.

sampling site	^{137}Cs (Bq/kg)
forest	16.40
banana orchard	14.82
cashew orchard	12.28
pineapple plantation	11.23

Table 1 shows ^{137}Cs accumulation of forest, banana orchard, cashew orchard and pineapple plantation were 16.40, 14.82, 12.28 and 11.23 Bq/kg, respectively. More detail data are in Table 2. The results from this study implied that ^{137}Cs accumulation for different land uses is related to with the soil erosion. Therefore, ^{137}Cs technique could be used as a tool for soil erosion evaluation in Thailand.

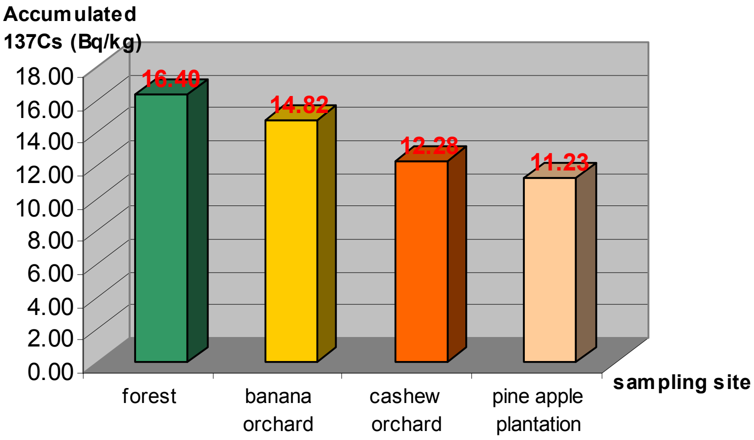

Figure 2. **^{137}Cs accumulation associated with different land use in study area.**

Table 2. The ^{137}Cs accumulation in different land uses related with the different slope.

Sampling site	Cs-137 (Bq/kg)	Slope (%)
Forest		
A11	20.53	31.73
A12	12.02	64.79
A13	16.65	47.23
Banana orchard		
B11	12.30	3.20
B12	19.86	2.96
B13	12.30	2.42
Cashew orchard		
C1	14.41	5.89
C12	13.92	6.03
C13	8.50	5.75
Pineapple plantation		
D11	8.71	25.74
D12	10.34	29.92
D13	14.64	25.53

Conclusion

The land use type in Haui Raeng -Klongpid watershed affected on ^{137}Cs accumulation in soil in each area. The ^{137}Cs accumulation in soil profile upon difference agricultural practice can be applied further for soil erosion study in Klongpid- Klonglod Watershed, Trat Province. Erosion is an important problem for land resources conservation in Thailand. There is a need to obtain the quantitative data concerning erosion in the watershed for the management solutions. The sing ^{137}Cs technique would be useful tool to evaluate soil erosion. Use of the ^{137}Cs technique has been limited in Thailand. Therefore, the results from this study could contribute to the value information as a preliminary investigation of soil erosion of watersheds in Thailand.

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Application of reduce tillage with a strip tiller and its effect on soil erosion reduction in highland agriculture

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Abstract

A tiller consisting of a 4 rows strip tillage device and fertilizer applicator was developed for reduced tillage and its effect on soil and fertilizer loss in field application was tested. The field was tilled at 10 cm width and at 10 cm depth by the equipment which was 16.7% of full-width tillage. The working performance and fuel consumption of the equipment were 3.8 hours/ha and 24.4 liter/ha respectively, which were 59% and 74% less than those of the conventional tillage. Fertilizer efficiency of the equipment in cultivation of 7 crops including Chinese cabbage was 1.5~1.8, 1.4~2.1 and 1.2~1.6 times higher in nitrate, phosphorous and potassium respectively, than conventional tillage. When the equipment was used after covering of rye residue, the quantity of runoff was 49~67% lower than the conventional tillage. The quantity of soil loss were 1.3 and 0.2 ton/ha right after and 30 days after planting of Chinese cabbage respectively, and 11.5 and 4.1 MT/ha in conventional tillage. In conclusion, the strip tillage equipment developed in this study can be applicable to slope land, so that soil loss can be decreased by 90%.

Key Words

Reduced tillage, strip tiller, soil loss, fertilizer loss, highland agriculture.

Introduction

Since highland agriculture in Korea has been developed in mountainous area with high slope, the agricultural lands are mostly with high slope. The conventional tillers used by farmers are apt to disturb surface soil heavily, and causes severe soil erosion. The fertilizer application using the conventional method spreading on surface before rotary cultivation also is subject to loss at rainfall events. Reduced tillage minimizing soil disturbance might reduce soil erosion (Luna 2003; Peterson 2004), and so site application of fertilizer might be decreased. This study is to develop a tiller for reduced tillage, and to test field applicability for sloped land in highland conditions.

Material and methods

Strip tiller development

A four row strip tiller with 12 tilling blades modified from Park *et al.* (2002) is shown in Figure 1. The distance of tilling blades was 60 cm (Figure 1b), and plain blades were attached at both side ends to protect soil and fertilizer from spreading outside. The tiller was attached to a 65HP tractor. The working performance and fuel consumption was analyzed as Park (2002). There were 3.8 hours/ha and 24.4 liter/ha respectively, which were 59% and 74% less than those of the conventional tillage operated with plow (data not shown).

Figure 1. A four row tiller designed for reduce tillage.

Field test for reduced tillage in sloped land of highland agriculture

A field experiment was conducted on a farm of which soil was silty clay loam with the 10 percent slope located on 750 m elevation in Hoenggye-Ri, Daegwallyeong-Myun, Pyeongchang-Gun, Gangwon-Do. The size of the field was 70 X 25 m^2. The 7 crops including Chinese cabbage, radish, cabbage, lettuce, soybean and corn were planted to evaluate effectiveness of reduced tillage and conventional tillage. The basal fertilizer application for Chinese cabbage was $83N\text{-}30P_2O_5\text{-}39K_2O$ kg/ha. The row distance was fixed at 60 cm, and the planting distance was 35 cm for Chinese cabbage, 25 cm radish and soybean, 45 cm for cabbage, and 30 cm for lettuce and corn, respectively, as RDA recommendation (RDA 2003). The harvesting date was 45 days after planting for lettuce, 60 days for Chinese cabbage, 75 days for cabbage, and radish, and 90 days for soybean and corn. During the cropping period, soil and fertilizer loss by water erosion at every rainfall events was monitored by simple lysimeter catchment installed in the field. The soil and plant samples were taken after harvest, and N, P and K nutrient contents were analyzed according to soil and plant analysis methods (NIAST 2000).

Figure 2. Lysimeter catchment to collect runoff and soil loss for conventional tillage (left), reduced tillage (center) and reduced tillage with rye mulching of Chinese cabbage.

Results

Strip tiller development

The tiller was attached to a 65HP tractor. The working performance and fuel consumption analyzed as Park (2002) were 3.8 hours/ha and 24.4 liter/ha respectively, which were 59% and 74% less than those of the conventional tillage operated with plow (data not shown).

Runoff and soil loss from reduced tillage

Figure 2 shows soil surface condition after intensive rainfall event at early stage of Chinese cabbage. As surface coverage was low due to young plant stands, severity of soil erosion from the ridge clearly shows in order of the conventional tillage, reduced tillage, and reduced tillage with rye mulching. Soil loss from the conventional tillage plots after 280 mm rainfall event from July 23 to 26 were 4.1 to 11.5 MT/ha, while that from the reduced tillage plots was 2.2 to 2.4 MT/ha (Table 1).

Table 1. Runoff, turbidity and soil loss from conventional tillage and reduced tillage with of without rye mulching.

	Planting date	Runoff (m^3/ha)	Turbidity (NTU)	Soil loss (MT/ha)
Conventional	July 21 1)	857	10,906	11.5
	June 25 2)	1,167	961	4.1
Reduce tillage	July 21	429	1,162	2.4
	June 25	920	649	2.2
Reduced tillage with rye mulching	July 21	286	357	1.3
	June 25	596	81	0.2

* Rainfall event : 280 mm from July 23 to 26
1) Lysimeter with 10% slope
2) Lysimeter with 17 % slope

The soil loss from the reduced tillage with rye mulching was 0.2 to 1.3 MT/ha, which was 1/2 to 1/9 of soil loss from the conventional tillage. The runoff from conventional tillage amounts 857 to 1,167 M^3, which was 30.6 to 41.7 percents of the total rainfall amount during this rainfall event. It reduced to 15.3 to 32.9 percent for the reduced tillage, and to 10.2 to 21.3 percent for the reduced tillage with rye mulching. The turbidity of the runoff ranged 961 to 10, 906 NTU from conventional tillage, and 649 to 1,162 NTU from reduced tillage and 81 to 357 NTU from the reduced tillage with rye mulching, respectively. These results clearly indicate that reduced tillage cut down soil loss and runoff, and thus improved runoff water quality.

Effect of plant growth and nutrient uptake

Table 2 shows plant growth and nutrient uptake at 40 days after planting. Reduced tillage increased plant growth for all tested crops by 34 to 61 percent on a dry matter basis. The nutrient uptake of the crops was also increased by reduced tillage in comparison with conventional tillage by 50 to 75 percents for nitrogen, 47 to 105 percent for phosphorus, and 28 to 61 percent for potassium. This result revealed that fertilizing methods could drastically affect the effectiveness of applied fertilizers. Conventionally, all fertilizers were wide spread on the surface of soil before planting and were incorporated by mixing soil with a rotary cultivation. In reduced tillage, fertilizers were applied in a band where the crop grew. Little physiological defect was found due to over fertilizing on site. More detailed examination on site specific fertilizing effect should be performed for different soils and plants.

Table 2. Plant growth and nutrient uptake at 40 days after planting.

Cropping		Fresh Crop (kg/ha)	Dried yield (kg/ha)	Nutrient uptake (kg/ha)		
Crop	Tillage			T-N	P_2O_5	K_2O
Chinese Cabbage	Conventional	24,805	1,609	58	25.1	54
	Reduce tillage	41,885	2,163	96(166)	39.0(157)	79(148)
Radish	Conventional	5,164	371	11	2.2	6
	Reduce tillage	8,209	532	27(171)	7.6(188)	18(148)
Soybean	Conventional	2,880	442	24	3.6	10
	Reduce tillage	4,041	602	36(150)	5.3(147)	12(124)
Lettuce	Conventional	8,255	446	19	3.2	18
	Reduce tillage	13,411	658	33(170)	5.7(179)	29(161)
Red cabbage	Conventional	5,623	521	24	4.3	13
	Reduce tillage	8,849	743	41(167)	8.8(205)	19(146)
Cabbage	Conventional	9,575	796	38	6.8	21
	Reduce tillage	12,361	1,051	59(157)	12.1(176)	26(128)
Corn	Conventional	11,696	1,035	39	8.5	37
	Reduce tillage	17,860	1,668	69(175)	14.5(170)	52(141)

Additionally, according to evaluation of workability and costs of operation, the fuel requirement for conventional tillage was 92.8 L which included plowing-harrowing-ridging, while 24.4 L for reduced tillage. The reduced tillage saving fuel consumption in the field by 74 percent, and might help farm economy.

Conclusion

The experimental results clearly showed that reduced tillage reduced soil erosion and runoff, and thus decreased turbidity of the runoff water. Especially, reduced tillage with rye mulching on soil surface doubled the effect of reducing soil erosion. Increasing surface coverage by rye mulching reduces raindrop impacts, and reduces water flow through rills. Decreasing runoff caused increasing infiltration, which might increase soil water reserve efficiency, and improve filtering effect of water. The reduced tillage also saved fuel consumption (Park 2002). Therefore, use of strip tiller for reduced tillage could be strongly recommended to reduce soil erosion and to improve farm economy. This might also improve water quality downstream of the highland agriculture.

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Artificial culture of biological soil crusts and their effects on runoff and infiltration under simulated rainfall on the Loess Plateau of China

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Abstract

On the Loess Plateau of China, biological soil crusts were artificially cultured in the laboratory, and then its effects on runoff and infiltration were studied under simulated rainfall. The results showed that (1) it was feasible to artificially culture biological soil crusts dominated by moss in the laboratory, and biological soil crusts inoculated by sprinkling crushed fragments of stems and leaves of natural biological soil crusts would almost completely cover the soil surface after about 15 months; (2) The artificially cultured biological soil crusts would significantly increase infiltration and subsequently decrease runoff, and the effects were positively linearly correlated to the surface coverage by biological soil crusts; (3) the effect of slope gradient on the partition of water between infiltration and runoff on biological soil crusts was similar to bare soil, but it seems that the effects of biological soil crusts in increasing infiltration and decreasing runoff may be more effective on steep slopes than on gentle slopes; (4) the start time of the runoff process was delayed by the presence of biological soil crusts, and also the soil-water redistribution process of biological soil crusts is significant than that of bare soil. These results may be useful for helping to control desertification by biological soil crusts in the Loess Plateau of China or similar regions.

Key Words

Soil and water loss; soil hydrology; desertification control; harsh environments

Introduction

Drought, concentrated rainfall, loose particles of loess soil, complex landform and long-term improper land use interact with each other on the Loess Plateau of China, and result in very sparse vegetation and consequently the most serious water loss and soil erosion (Cha and Tang 2000). However, the biological soil crusts (BSCs), which are defined as a complex mosaic of soil, cyanobacteria, green algae, lichens, mosses, microfungi and other bacteria by Belnap and Lange (2003), are extensively distributed under the shadow or between the sparse vegetation (Zhao *et al.* 2006). However, the ecological functions of these crusts are not clear. The serious soil-water loss, extensively distribution and potential important functions of biological soil crusts in soil and water conservation (Eldridge 1993; Belnap *et al.* 2005) imply that these crusts may play a critical role in the remediation and restoration of fragile ecological environment on the Loess Plateau of China. The objectives of this research were to (1) evaluate the prevalent artificial culture method of biological soil crusts on the Loess Plateau of China, (2) describe the preliminary differences between artificial cultured biological soil crusts and natural crusts in appearance and composition, and (3) quantitatively assess the influences of artificial cultured biological soil crusts on infiltration and runoff.

Methods

Artificial culture of biological soil crusts

The loess soil was collected and sifted through a sieve with 10 mm diameter. Then the prepared soil was packed into 8 boxes (1.0 m× 0.4 m× 0.4 m) by 1.3 g/cm^3. Afterward, the natural biological soil crusts collected from field were crushed and mixed with some fine soil, and seeded uniformly (inoculation dose of air dry matter is 1.25 kg/m^2). The simulated rainfall experiment was started when the cultured biological soil crusts were initially formed. The rainfall intensity and duration were as applied at 50 mm/h for 1 or 1.5 hours, respectively. In this study, nntwo factors including coverage of crusts (bare soil and biological soil crusts with different coverage at different growth days) and slope gradient (9%, 18%, 27%) were considered. The simulated rainfall was repeated 3 times in 376 days (trial a), 414 days (trial b) and 448 days (trial c) after the inoculation of biological soil crusts.

Measurement and data analysis

The coverage of biological soil crusts in boxes was calculated from the pictures that were obtained by a high resolution camera by Supervised Classification in Erdas Imagine 8.7, and then validated and corrected on the basis of personal experience (Pan and Shangguan 2005). In the simulated rainfall experiment, the runoff from every soil box was collected and measured every 2 minutes from starting point to the end. The soil water profile was also measured before, after and about 24 hours after rainfall respectively by TDR (TRIME-EZ, IMKO in Germany) at interval of 5 cm. The coverage of biological soil crusts was classified by K-Means Cluster in SPSS 15.0 for Windows. The different classes imply different treatments for the coverage of biological soil crusts. The experimental data were analyzed using Descriptive Analysis and one-way ANOVA by SPSS 15.0.

Results

Relationship between runoff-infiltration and coverage of biological soil crusts

According to the classification results of the coverage of biological soil crusts, 8 soil boxes can be classified to 3 classes in trial a (No. 1, 2 for bare soil; No. 3, 4, 5, 6 for biological soil crusts averaging coverage 29.12%, labelled 29% BSC; No. 7, 8 for biological soil crusts averaging coverage 60.97%, labelled 61% BSC), and also 3 classes in trial b (No. 1, 2 for bare soil; No. 3, 5 for biological soil crusts averaging coverage 40.01%, labelled 40% BSC; No. 4, 6 7, 8 for biological soil crusts averaging coverage 78.17%, labelled 78% BSC). Statistic analysis by one-way ANOVA show that there are significant differences among these 3 classes (F=95.520, $P \leq 0.001$ for trial a; F=19.537, P=0.012 for trial b). Therefore, 8 soil boxes can be regarded as 3 treatments (bare soil, 29% BSC and 61% BSC in trial a; bare soil, 40% BSC and 78% BSC in trial b).

The cumulative runoff during simulated rainfall in trial a and trial b were presented in Figure 1. In trial a, the entire runoff process was delayed about 10 minutes by the presence of the biological soil crusts from the comparable results of start time at initial stage (about 20 minutes for bare soil and 30 minutes for 29% BSC) and steady state (about 38 minutes for bare soil and 49 minutes for 29% BSC). However, this effect was not clear in trial b, possibly due to the 9% slope gradient and the relative higher initial soil water content that was the result of rainwater infiltration in trial a. The experimental data from the steady state was linearly fitted (y=ax+b), and parameter a, which from the slope gradient of the fit line was equal to the steady runoff rate listed in Table 1. Also, the comparable results of the runoff coefficients, which is the percentage of total runoff to total precipitation, show that the runoff coefficient was decreased 33.33% by 29% BSC and 100% by 61% BSC in trial a, decreased 41.79% by 40% BSC and 59.70% by 78% BSC in trial b.

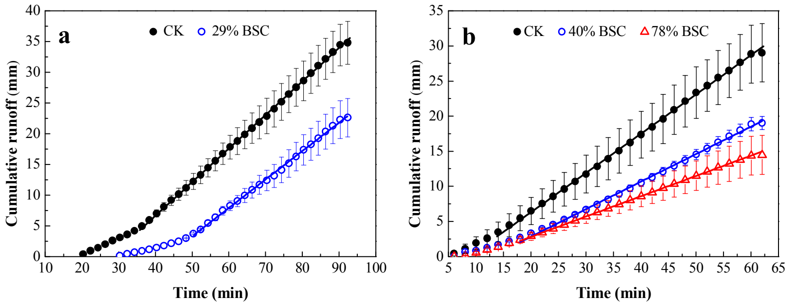


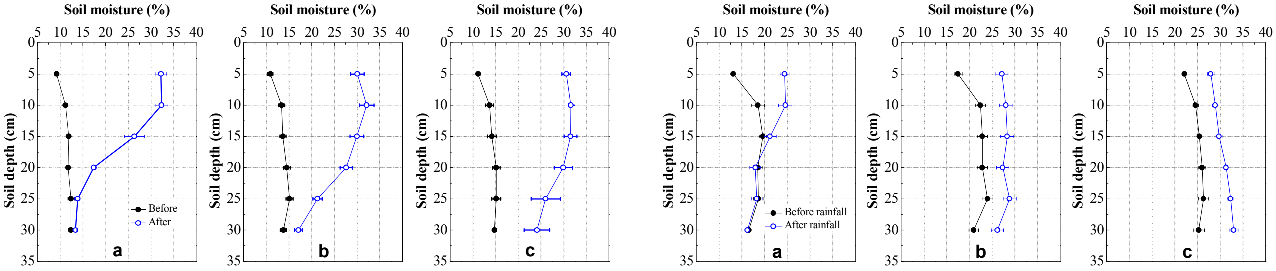
Figure 1. Cumulative runoff versus time during the trial a (a) and trial b (b).

Table 1. Total precipitation, infiltration, runoff, steady runoff rate and runoff coefficient of trial a and trial b.

	Trial a			Trial b		
	Bare soil	29% BSC	61% BSC	Bare soil	40% BSC	78% BSC
Precipitation (mm)	75.62^{a}	74.51^{a}	67.22^{b}	45.37^{a}	49.89^{a}	48.98^{a}
Runoff (mm)	34.46^{a}	22.28^{a}	0.00^{b}	29.03^{a}	19.62^{ab}	14.47^{b}
Steady runoff rate (mm/min)	0.55^{a}	0.46^{b}	0.00	0.56^{a}	0.39^{a}	0.29^{a}
Infiltration (mm)	41.18^{b}	52.24^{ab}	67.22^{a}	16.34^{b}	30.27^{a}	34.51^{a}
Runoff coefficient	0.45^{a}	0.30^{a}	0.00^{b}	0.67^{a}	0.39^{b}	0.29^{b}

The different letter in same row means it has significant differences at 5% probability level

The soil moisture profile measured before and after rainfall in trial a and trial b are presented in Figure 2. The infiltration depth can be easily inferred from the intersection of soil moisture profiles. This infiltration depth is 25 cm for bare soil, 30 cm for 29% BSC, far more than 30 cm (which is the maximum of monitoring depth) for 61% BSC in trial a, and 20 cm for bare soil, much more than 30 cm for biological soil crust (both for 40% BSC and 78% BSC) in trial b. It indicates that the infiltration depth was significantly increased by the biological soil crusts. In other words, the infiltration was encouraged by the presence of biological soil crusts. Except for infiltration depth, the amount of infiltration water could also be calculated from the soil moisture profile. It should be noted that the total infiltration determined from soil moisture is in agreement with the infiltration, which is subtracted total runoff from total precipitation according to the principle of water balance. This result implies that TRIME-EZ has good accuracy and precision in the measurement of soil moisture.



Trial a Trial b

Figure 2. Soil moisture profile before and after rainfall in trial a (a. bare soil, b. 29% BSC and c. 61% BSC) and trial b (a. bare soil, b. 40% BSC and c. 78% BSC). The infiltration depth can be determined from the intersection of soil moisture profiles.

Relationship among runoff-infiltration, slope gradient and presence of biological soil crusts

In trial c, the biological soil crusts almost completely covered the soil surface in each soil box. Thus the coverage of cultured biological soil crusts in each soil box was considered to be 100%. So another critical factor, slope gradient, which largely decides the partition between infiltration and runoff during rainfall was studied instead of coverage of biological soil crusts.

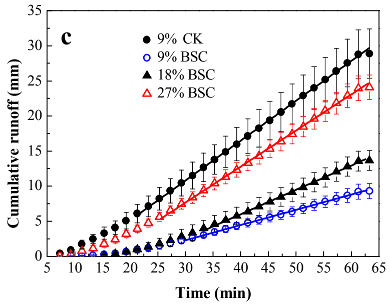


Figure 3. Cumulative runoff verses time during the trial c. The coverage of biological soil crusts in here is almost 100%, and the percentage in legend means the slope gradient.

From Figure 3 and Table 2, we can find that the runoff coefficient was largely decreased 67.24% by biological soil crusts as compared to bare soil. Also, the runoff coefficient of biological soil crusts is increased 36.84% at 18% slope gradient, and increased 136.84% at 27% slope gradient as compared to that at 9% slope gradient. However, the runoff coefficient of biological soil crusts increased 36.84% when the slope gradient increasing from 9% to 18%, and increased 73.08% when the slope gradient increasing from 18% to 27%. This trend of runoff coefficient changing with slope gradient may imply that the protection of biological soil crusts may be more effective under steep slope conditions than gentle slope conditions.

Table 2. Total precipitation, infiltration, runoff, steady runoff rate and runoff coefficient of trial c. The coverage of biological soil crusts in here is almost 100%, and the percentage in legend means the slope gradient

	9% bare soil	9% BSC	18% BSC	27% BSC
Precipitation (mm)	50.08^{a}	50.12^{a}	51.62^{a}	54.04^{a}
Runoff (mm)	28.90^{a}	9.30^{b}	13.66^{b}	24.08^{a}
Steady runoff rate (mm/min)	0.57^{a}	0.22^{b}	0.35^{b}	0.51^{a}
Infiltration (mm)	21.19^{c}	40.82^{a}	37.96^{a}	29.97^{b}
Runoff coefficient	0.58^{a}	0.19^{c}	0.26^{c}	0.45^{b}

From the soil moisture profile before and after trial c, we can also infer that the infiltration depth is about 15 cm for bare soil with 9% slope gradient, 25 cm for biological soil crusts with 27% slope gradient, 30 cm for biological soil crusts with 18% slope gradient, and more than 30 cm for biological soil crusts with 9% slope gradient. It implies that infiltration was largely increased by biological soil crusts and decreased by slope gradient. In trial c, the soil moisture profile was also measured 18 hours after the rainfall in order to evaluate the differences of soil water redistribution process among the 4 treatments as the soil water redistribution process is a very important way which can be used to evaluate the water holding capacity of soil. Finally we found that the soil water redistribution process of biological soil crusts is significant than bare soil. Thus we can conclude that the soil water redistribution process may be largely affected by biological soil crusts.

Conclusion

All collected experimental data was used to analysis the correlation among runoff coefficient, slope gradient and coverage of biological soil crusts. The histogram, P-P plot and partial regression plot in linear regression results unanimously confirm that the variables satisfied linear distribution, and prove that the regression function passed the test for homogeneity of variance. The resulting regression function is $y=1.278x_1-0.417x_2+0.490$ ($F=12.547$, $P<0.001$, x_1 is slope gradient, x_2 is coverage of biological soil crusts, and y is runoff coefficient). From the regression function, we can find that the runoff coefficient is positive to slope gradient and negative to coverage of biological soil crusts. If we only consider the effects of biological soil crusts, we can get a good linear relationship between the coverage of biological soil crusts and decreased runoff (Figure 4). The correlation coefficient ($r=0.9737$) suggests that this linear relationship is statistically significant at 1% probability level (the critical value of r at 1% probability level is 0.7980).

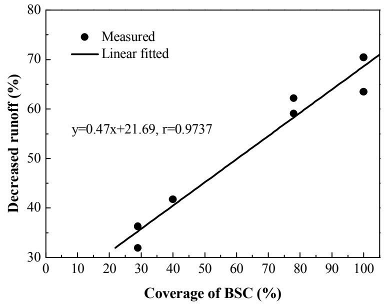


Figure 4. Linear relationships between coverage of biological soil crusts and decreased runoff.

From the three simulated rainfall experiment we can conclude that: (1) it is feasible to artificially culture biological soil crusts dominated by moss in laboratory, and biological soil crusts inoculated by sprinkling crushed fragments of stems and leaves of natural biological soil crusts will almost completely cover the soil surface after about 15 months; (2) the artificial cultured biological soil crusts will significantly increase infiltration and subsequently decrease runoff, and the effects is positively linearly correlated to the coverage of biological soil crusts; (3) the effects of slope gradient on the partition between infiltration and runoff on biological soil crusts is similar to bare soil, but it seems that this effects of biological soil crusts in increasing infiltration and decreasing runoff may be more effective for steep slope than gentle slope; (4) the start time of the runoff process was delayed by biological soil crusts, and also the soil water redistribution process of biological soil crusts is clearer than for bare soil.

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Bioinformatics for the Albertine Rift: A roadmap and infrastructure for a virtual regional research centre for applied biodiversity in Rwanda, Africa which integrates biological and geographical information including soils

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Abstract

In 2008 Maxine Levin, Soil Scientist, USDA-Natural Resources Conservation Service participated in a US Embassy Science Fellowship in Kigali Rwanda. She was hosted by the Rwandan government and the US Embassy to work in the Ministry in the Office of the President (His Excellency Paul Kagame) in charge of Science and Technology under Minister Roman Murenzi. At the request of the Ministry, an extensive review of facilities, resources and databases was conducted to give advice and support to the planning of a regional research center for biodiversity. Analysis of Rwanda's present infrastructure showed a need for a regional data sharing policy as well as a focus on integration of all geographical (soils, geology, topography and land use) and biological (vegetation and wildlife) databases.

Key Words

Bioinformatics, Rwanda, data integration, geographic information systems, biodiversity

Introduction

Rwanda, a small, highland agriculturally-based country in Central Africa has undergone an environmental revolution since its devastating civil war and genocide in 1994. During the First International Research Conference on Biodiversity Conservation and Sustainable Natural Resource Management in Kigali Rwanda, July 2007, His Excellency Paul Kagame, President of the Republic of Rwanda, made a commitment to achieve socioeconomic development while preserving Rwanda's ecological integrity. The message "environmental protection is everybody's business" was expressed directly as part of the national development vision. He encouraged the leadership at the conference to shift into a new mode of thinking—a new business model—in which the protection of biodiversity will be viewed as a viable business opportunity for new products both in mainstream enterprises and small business prospects. Proposed Rwandan land policies that will ensure conservation, protection and economic viability were deemed equally important to the future of Rwanda. Recommendations of the Rwandan executive government acknowledged that Rwanda needed to adequately map and inventory the biodiversity of the Albertine Rift, acknowledge this important internationally designated "Biological Hotspot" (designated by Conservation International in 2006) and conserve, protect and manage Rwanda's national assets. The Government of Rwanda identified a need to improve its institutional capacity to do continuously monitor species and do scientifically innovative research in the field of applied biodiversity. At the conference His Excellency Paul Kagame wanted the participants to explore the idea of a regional approach to the establishment of a research center for biodiversity and natural resource management that pools the human resources of the entire region. He encouraged the long term commitment to this international partnership initiative to improve biodiversity and natural resources management in Rwanda and entire region.

Rwanda is known as the "Land of One Thousand Hills. In Rwanda, agriculture is mainly subsistence and occurs on small plots, often on extremely steep slopes. Naturally fertile soils in western Rwanda are prevalent with influences of volcanic ash downwind from the greater Virunga volcanic range. In eastern Rwanda, the climate is drier, the soils are less fertile, shallow, granitic bedrock-based. The gravelly soils are on flatter slopes but in many cases because of removed surface biomass, more sensitive to erosion. Since the late 1990's many refugees have moved into these areas to farm as well as graze increased cattle herds. Some statistics show decreased agricultural production throughout the region despite an influx of farmer and agriculture development support. In East Africa, the Great Rift Valley divides into two, the Western Rift Valley and the Eastern Rift Valley. The Western Rift, also called the Albertine Rift, is edged by some of the highest mountains in Africa, including the Virunga Mountains, Mitumba Mountains, and Ruwenzori Range. The Albertine Rift spans the national boundaries of 6 East and Central African countries, Uganda, Democratic Republic of the Congo, Rwanda, Burundi, Tanzania, and Zambia. Rwanda, (though a small part of the Albertine Rift), lies mid-range in the region and is centrally located for access. The Albertine Rift has been identified as a “Biological Hotspot” by Conservation International for its wide range of endemic species and its susceptibility to degradation and change due to human socio-economic and population pressures.

Public funded biodiversity information provides an unbiased level playing field for integrated decision making for the best use of land, economic development and conservation of Rwandan and the Transboundary Albertine Rift’s natural resources. What makes economic sense for the regional development and conservation of the Albertine Rift needs to be a balance of public good, service-oriented infrastructure, sound governance, sound science, and regional human resource capacity. The demand for integrated land and biodiversity information is growing and requests for specific data and analysis are constantly evolving and continually changing. Demand is driven by change in agricultural program policy, land use changes, and evolving land-use law, regulation, policy and environmental concerns in the developing economy and well being of Rwandan national land base and population. Inventory and monitoring require continual improvement in order to assure an accurate and complete database that can satisfy evolving needs for data and analysis. In addition, potential climate change and the ensuing adaptation strategies are pushing East and Central African Nations towards more cooperation and the need for a regional approach to strategies as a mode of survival. Based on its focus of improving the lives of its people and those of the entire region with innovative uses of science and technology, Rwanda is at a point in its political and socio-economic recovery and development to support a service-based integrated database infrastructure for the region

Status of Integrated Databases in Rwanda

Since the early 1970s various biological scientists from many countries have inventoried general biological information on the Albertine Rift and monitored specific species for prevalence and resilience. The data is scattered through a variety of sources, some published and open to public and ministries through purchase of scientific journals and books. Most of the data has been monitoring data from protected areas that is proprietary by the collector or institution that conducted the field work. The raw data is available only in a limited sense to protect the investment scientifically and monetarily of the original investor of the work. In many cases the information is not in an electronic format and cannot be integrated without restructuring the data and inputting into a database.

Rwanda has made great strides in providing data infrastructure with a pilot within the National University of Rwanda (NUR) Center for Geographical Information Systems (CGIS)—the Geo Data Portal. The CGIS is a learning and research center created about 9 years ago. First supported by the NGO Dian Fossey Gorilla Research Fund to push forward spatial analysis of biological monitoring data, the Center’s primary focus has been to build capacity in GIS in Rwanda through education and pilot projects. The pilot projects demonstrated the intrinsic usefulness of integrated spatial analysis of biological, agricultural, market-based, community planning and human resource problems and best use management planning. Soil Survey data, a primary source for land based GIS analysis, was collected in the 1970’s and 80’s in Rwanda. It is digitized but not readily available to the science and agricultural community or to this Center.

At this point the basic framework of the Geo Data Portal is functioning. Its purpose is to funnel geographic land data from the different Rwandan Ministries to a controlled accessible site for intranet users. Control of the databases and certification of the data still lies with the Ministry or Investigator of origin. Integration of information spatially can start to take place between Ministries. At this time, CGIS is ready to hand off the maintenance and day-to-day functioning of the Portal to an appropriate neutral party and continue its education and demonstration project activities. Many of the applicable land-related databases already reside or will reside with the Rwandan government National Land Center. The Rwandan Information Technology Agency however has the expertise to provide neutral server and maintenance functions for the Portal and may be the best host at this time.

Technical Advantages to Bioinformatics Open Platform and Integrated Data Analysis with Geospatial land information

Integrated data analysis (on applied biodiversity questions) is best done as a team. With 3 to 5 virtual technical specialists as a team, it allows some to specialize in certain areas such as geospatial technologies (GPS, GIS and remote sensing) for landscape analysis (topography, vegetation, climate, geology, and hydrology), biological and soil data comparison, microbiological and chemical data analysis and population, biological taxonomy and classification, etc. This leads to improved team performance, job satisfaction, and improved quality of the database, monitoring and inventory. Use of Ecological Site Descriptions with state and transition models have an excellent potential to portray and integrate biological and land based geographical data in a format easily understood by many of the disciplines. For building human capacity there is a trove of information about ecological landscapes, animal-plant-habitat interactions and synergies, animal behavior, etc. that can not be gained except through on the job training with seasoned scientists experienced in an area. Thus the field work needs to be place-based with teams working closely together in the locations where the data is to be collected. The documentation, analysis, archiving and distribution should be centralized virtually for maximum efficiency.

Organization Functions, Structure and Staffing

There are 4 major Divisions for the proposed virtual regional research center: "Inventory and monitoring", "GIS/Information Technology Services", "Laboratory Services", and "Education".
The primary objective of the New Organization Structure Plan and Staffing recommendations is an efficient and effective organization to produce and maintain a consistent, seamless, digital inventory of the Transboundary Region of the Albertine Rift. A secondary objective of the new organization structure would be to assure that all lands and lake areas within the region will be inventoried and updates (through monitoring protocols) will be done on a continuous basis. The focus of the organization is on providing virtual service infrastructure to all active stakeholders in the region of the Albertine Rift. The emphasis on investment in virtual infrastructure would be to enhance present capacity for Rwanda and Rwanda's neighboring countries' institutions, committed international researchers and universities and active non-governmental organizations (NGOs) through service in providing tools for integration and standardization of data. Institutions already in place and working effectively should not be undermined by rather enhanced by the service of the virtual regional research facilities.

Establishing a service-oriented Virtual Regional Research Center for Applied Biodiversity with integration of land and biologically related data by 2010

With the consolidation of both monitoring and reference data and integration of land related data through a Geo-data Portal, a Virtual Regional Research Center for Applied Biodiversity is possible by December 2010 and is moving forward with support by the Rwandan government. This process can be enhanced by:

1. Focusing public service and contracted staff from some monitoring activities to data input and consolidation from published information, meta-data attached data identifying source.
2. Clarifying science policy of data sharing, public information for the public good, proprietary restrictions of data collected with public funds or on public lands.
3. Establishment of public service laboratories for production soil lab testing, genomics, biological and botanical taxonomy and microbial analysis and identification, preferably in a centralized location with appropriate transport and infrastructure capacity
4. Establishing and electronic virtual reference library of pertinent biological, meteorological, atmospheric and land data for the Albertine Rift that is public in nature for use by educators, public service land managers and scientists.
5. Working with NGO partners and already established Technical Networks-- Wildlife Conservation Society, Dian Fossey Gorilla Fund International, Conservation International, Great Apes Fund of Iowa, CARPE, ARCOS, Transboundary Secretariat for the Albertine Rift, GRASP
6. Supporting Satellite Centers such as Karisoke Research Center, ORTPN Interpretation Facilities in the National Parks and Protected Areas
7. Focusing funding to endowment strategies to provide consistent funding for permanent staff, maintenance and replacement of supplies and equipment on a 2-4 year cycle
8. Focusing project research funding on product development and production problems with integrated teams of biological, environmental chemistry and mechanical engineering research scientists
9. Supporting central laboratories and satellite research facilities with information technology technical support hardware and software maintenance either through NUR and KIST IT staff or Ministerial partnership

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Canopy cover and organic matter spatial distribution as indicators of soil quality for aquifer recharge

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Abstract

Maintaining perennial rivers, with water emerging in springs, is directly related to soil management, as this will determine the groundwater flow in recharge areas. Rational management in a watershed requires knowledge of several important parameters regarding the hydrology, including vegetation cover and soil organic matter (OM) amounts. The objectives of this study were to identify the existence of vegetation using the normalized difference vegetation index (NDVI) and analyze the spatial variability of the organic matter (OM) amount, in order to identify favorable points of carbon stocks and groundwater recharge in the Salto and Pitangueiras Sub-basins that are part of Jaguari River Basin. Both sub-basins are located in the county of Extrema (Minas Gerais, Brazil). For vegetation analyses, the Landsat-5 TM images acquired on Sept. 03, 2008 (INPE 2009) were used. In addition, geostatistics and kriging were performed to determine the OM spatial variability. The study area was primarily occupied by degraded pastures with dense vegetation mainly in the headwater basin. In most of the study area, there were moderate amounts of OM, with higher levels of OM in areas of high and low altitude. The study area is occupied by degraded pasture, which has less potential for carbon storage when compared to dense vegetation. Accordingly soil conservation can be impaired and thus recharging groundwater and water quality as well.

Key Words

Cantareira system, water resources, pastures, remote sensing, Atlantic forest, water producer program.

Introduction

In the southeastern region of Brazil, there is one of the largest drinking water production systems in the world (33 m^3/s); the whole reservoir system is called Cantareira. The Jaguari River Basin is the biggest tributary (22 m^3/s) for the System and for this reason it is considered a priority area for freshwater production in the country. Such regions have suffered many alterations by anthropogenic activities (69.4%). Areas covered by Atlantic Forest (native vegetation), which are essential for production and purification of water; occupy only 21% (ISA 2007). For the aforementioned reasons, the basin is part of the Water Producer Program, which aims to recover all basins with strategic importance for the nation development, through joint environmental management of water resources, land use within their ability to use and proper handling of animal production systems (livestock) and plant (agriculture and forestry) (ANA 2008). Maintaining the perennial of rivers, with water emerging in springs, is directly related to soil management, as this will determine the groundwater flow in recharge areas. Rational management in a watershed requires knowledge of several important parameters regarding the hydrology, including vegetation cover and soil organic matter (OM) amounts, consisting of the organic carbon (OC). The present study aimed to identify the presence of vegetation using the normalized difference vegetation index (NDVI) and analyze the organic matter spatial variability, to identify favorable points carbon stock and groundwater recharge in the Salto and Pitangueiras Sub-basins, part of Jaguari River watershed, which is located in Extrema County, Minas Gerais, Brazil.

Methods

The Salto and Pitangueiras Sub-basins together have an area of about 4,100 ha and are within the Jaguari River Basin in Extrema Co., MG, Brazil (22° 51'18"S, 46° 19'04"W) (Figure 1). The climate is tropical of altitude Cwb (Köppen, 1948), with an average 1,181 mm annual rainfall and 1,130 m altitude. The native vegetation is the Atlantic Forest (Figure 1). The soils found in sub-basins are Neosol, Cambisol, Red-Yellow Latosol, Red-Yellow Argisol, and Gleysol. For the vegetation analyses images from the satellite Landsat TM-5 was used. They were acquired on September 03, 2008 through the National Institute for Space Research - INPE (INPE 2009), where the image was made in the visible light (R: band 3, G: band 2, B: band 1), and the NVDI was processed using the following bands: bands 3 (red reflectance), and 4 (near infrared

reflectance) according to Rouse *et al*. (1973). Topographic effects are minimized when such index are applied, producing a linear measurement scale, which ranges from -1 (no vegetation) to +1 (high vegetation density). Information NDVI was processed using RSI-ENVI 4.5. The information network of drainage and slope were combined in ArcGIS 9.2 software in order to characterize the most degraded areas.
Soil samples were collected 47 points in the 0-20 cm depth. Organic matter was determined by hot oxidation with potassium dichromate and titration with ammonium ferrous sulfate as methodology of Raij and Quaggio (1983). The study of spatial variability and the choice of semivariogram model that best described the variability of the data were conducted using techniques of geostatistics and data interpolation by kriging, to predict and map soil organic matter amount in the region. All geostatistical analyses were made in the program through the R package GeoR (Ribeiro Jr. and Diggle 2001) and kriging in ArcGIS 9.2.

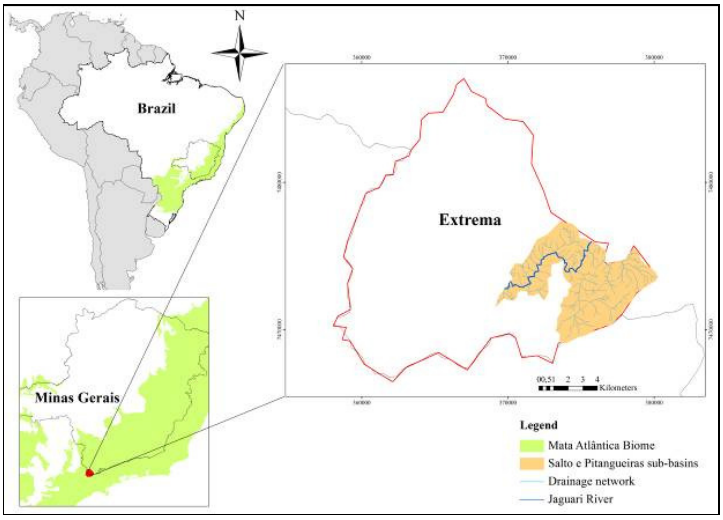


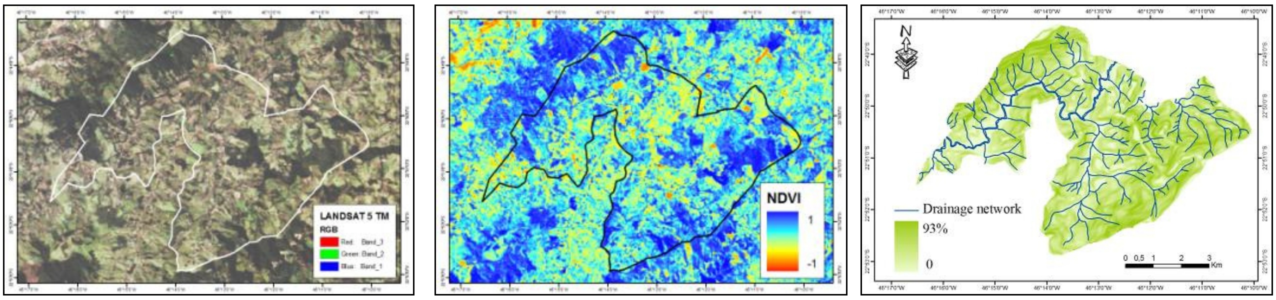
Figure 1. Location of the Extrema County in Minas Gerais - Brazil, highlighting the sub-basins studied.

Results

The RGB color composite from the amplitudes of the components 3, 2 and 1 (Figure 2a) helps in understanding land use and cover. Through that figure we can view the low vegetation cover, with large pastures use, it was also observed in the field. In Figure 2b, blue color shows areas of higher NDVI, while the cyan color shows areas of moderate NDVI and red tones indicate areas of low NDVI. The NDVI shows a vegetation from moderate to low in most of the study area (color cyan and yellow), followed by dense vegetation, i.e., with higher NDVI values. The lowest NDVI values (red areas in the map) characterize regions of exposed soil and therefore more prone to erosion. These areas, although relatively small, should be viewed carefully considering the moderate NDVI area, which can reduce or increase soil degradation depending on the grassland management (Figure 2b).

The study area was primarily occupied by degraded pasture, which undermines soil conservation, groundwater recharge, and water quality. Unlike what occurs in this kind of system, places with dense vegetation have soil that has: increase protection from the raindrop impact, increased water infiltration, level soil organic matter contents, and good soil aggregation. All these factors promote aquifer recharge. The vegetation looked at in relation to drainage and slope showed that the most areas susceptible to erosion (lower NDVI) were present along both the main network (Figure 2c), which were in the flatter areas (Figure 2c), and in the higher, steeper areas, where the highest degradation was observed. The dense vegetation was found mainly in the headwater area, however the worst soil degradation was also observed in these areas. In the more rugged topography areas the elimination of vegetation leads to a further advancement of erosion as when compared to the less steep areas. These NDVI results for grassland are important, considering that for this type of vegetation the index variation was not as intense during the year (Victoria *et al.* 2009) and can be used as a good indicator for the conservation conditions of soil and water.

The Table 1 and Figure 3 give the soil organic matter distribution for the study area. The OM ranged from 17.7 to 57.4 g /kg being classified as low to good. Only 0.1% of the area had low OM, 92.41% had moderate amounts, and the remainder 7.49%, were classified with good amounts of OM (Ribeiro *et al.* 1999). The presence of this attribute is very important as mitigate the raindrops impact, preventing compaction and splashed soil, altering pores distribution, facilitating water infiltration, and therefore creates favorable conditions for aquifer recharge (Junqueira Jr. *et al.* 2008). Comparing the OM and altitude maps, there are high amount of organic matter in both areas. Soil OM for higher altitude as the lower value, occurred possibly due to lower temperatures and oxygen restriction due to excess of water, respectively. It is noteworthy that the low areas the soil organic matter amounts were even more significant.



(a) **(b)** **(c)**

Figure 2. (a) Images from LANDSAT - 5 TM, composition of the visible spectrum RGB 321; (b) NDVI, (c) slope and drainage network, of the Salto and Pitangueiras Sub-basins in Extrema County, MG.

Table 1. Distribution of organic matter (OM) in the studied area.

Classes	Area	
g/kg	ha	%
< 20.0	3.93	0.10
20.0 – 30.0	747.48	18.20
30.0 – 40.0	3,047.17	74.21
> 40.0	307.56	7.49
Total	4,106.14	100

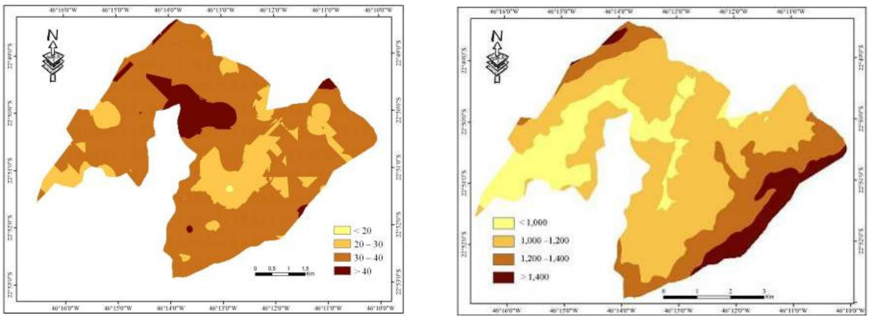


Figure 3. Spatial distribution of OM (g/kg) and altitude map (m).

Conclusion

The study area was primarily occupied with degraded pasture, which undermines soil conservation, groundwater recharge and water quality. The dense vegetation occurred mainly in the headwater basin. The OM had a moderate amount in most of the area, with high OM amounts in areas with higher and lower altitudes. The locations of dense vegetation, and where the organic matter amount was higher, indicated favorable points of carbon stock and aquifer recharge.

Acknowledgements

We thank the Research Foundation of the State of Minas Gerais (FAPEMIG) for financial support in this world congress.

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Nutrients Leached under Lychee Cultivation of an amended Northern Thai Highland Acrisol

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Abstract

Lychee cultivation in northern Thailand is a popular method to earn income for farmers. Fertilizer and soil amendments will always be recommend for improving soil properties. This experiment examines responses of selected soil amendments and NPK fertilizer on nutrients leached under lychee canopies of an Acrisol soil. An experiment was conducted with resin buried at 30 and 60 cm depth for 4 months. Chemical application cause more leaching of nutrients than other treatments. The amount of elements absorbed by resin at 30 cm. was large compared with 60 cm depth for all extractants. The contents of nutrients extracted by 0.5N HCl gave lower values than BrayII and NH_4OAc pH 7.0. The amounts of nutrients leached were at low levels for fly ash application. In addition, extractable S at 60 cm depth ranged from 73 to 133 mg/kg being higher than the amount of S at 60 cm depth of 54 to 86 mg/kg. The treatments resulted in various leaching conditions under lychee canopies for the Acrisol soil. More nutrients and heavy metals including trace elements should be analyzed.

Key Words

Nutrient, leaching, lychee and Acrisol.

Introduction

Nowadays, Lychee (*Litchi chinensis* Sonn.) cultivation areas in northern Thailand have been extended to many provinces (Sethpakdee 2002). Lychee orchards are the popular fruit trees to earn higher profit than others land uses. For the past decades, many areas have increasingly realized the effects of global climate change. As a result of this phenomenon in northern Thailand, lychee orchards migrated to higher elevations in order to experience a preferred climate. This increases the occurrence of deforestation and other environmental problems such as soil degradation and water pollution resulting from the use of chemical substances like fertilizers, pesticides and herbicides. In this condition, a sustainable development program should be developed on conserving the entire watershed environment by limiting agricultural activities that cause soil erosion and allow poisonous leachates to infiltrate streams and groundwater. Such events are dangerous for mankind, animals and the environment (Inthasan 2006). Leaching under lychee canopies should be measured. Various soil amendments such as dolomite, fly ash and chicken manure were selected for research and compared with chemical fertilizer applications. The capability of resin to adsorb elements should indicate subsoil leaching of nutrients in the Acrisol.

Methods

Research area

The experimental area was 35 km north of Chiang Mai, at Mae Sa Mai Valley in the Mae Rim district. The agricultural area covers over 1,000 hectares with most of it over 1,000 m above sea level. The period of rain starts from mid of April and continues for at least 6 months providing about 1,500 mm annually. Soil types in this research study is classified as Acrisol and is different from those highland soils in which pH is higher (6.0-6.5). A detailed geological map shows that this area is occupied by gneiss, granite and migmatite including some limestone, marble and freshwater limestone (Schuler *et al.* 2006).

Main study

Resin samples were buried at 30 and 60 cm depth under lychee canopies at the time of fertilizer application and left for 4 months (July-October 2007) within the rainy season. The lychee trees selected for this research work were contained in four replications of four treatments on the basis of one lychee plant per treatment. A randomized complete block design was assigned for this experiment. Those treatments were arranged as follows:

TRT 1. Control = C; farmer practice with N-P-K 2.5 kg/tree/year of 15-15-15
TRT 2. C+ dolomite 1.5 kg/tree/year
TRT 3. C+ fly ash (lignite fly ash) from electric power plant 1.0 kg/tree/year
TRT 4. Chicken manure 10 kg/tree/year

Analyses

All resins were taken from the soil after 4 months. Extractable P was determined by extracting the resin samples with Bray II and 0.5 N HCl and the concentration measured by spectrophotometer (Watanabe and Olsen 1962). NH_4OAc 1 N, pH 7.3 and 0.5 N HCl were used for K, Ca and Mg extraction. Exchangeable K was analysed by flame spectrophotometer. Exchangeable Ca and Mg were determined by Atomic Absorption Spectrophotometer (Jackson 1958), while extractable S was only analysed in 0.5N HCl extracts using a turbidimetric method (Black *et al*. 1965).

Results

The concentrations of P, K, Ca and Mg were higher for BrayII and NH_4OAc pH 7.0 extracts than 0.5N HCl (table 1 and 2). Extractable P (BrayII) at 30 cm ranging from 55 -293 mg/kg and significantly decreased to 26-58 mg/kg at 60 cm. The same trends were demonstrated for extractable K, Ca and Mg (by NH_4OAc pH 7.0). The application of fly ash with NPK fertilizer caused the lowest concentration all nutrients both at 30 and 60 cm compared with Control, C+dolomite and chicken manure additional. The increase in extractable K at 60 cm was significant. Dolomite application causes the highest content at 1,005 mg/kg but was not different from the chicken manure treatment that showed 925 mg/kg. Generally, dolomite caused higher amounts of extractable Ca and Mg in resin samples both at 30 and 60 cm than for other treatments. The contents were 2709 and 1,601 mg/kgCa and 407 and 296 mg/kgMg at 30 and 60 cm depth respectively. Content of extractable Ca in resin samples at 60 cm, in particular, was significantly higher. Similarly with 0.5N HCl extracting, the certain nutrients at 30 cm depth were detected less than 60 cm depth. The concentrations of extractable P, K, Ca and Mg were not significantly affected ranging from 29-74 mg/kgP, 200-665 mg/kgK, 185-1871 mg/kgCa and 68-296 mg/kgMg at 30 cm depth. The contents of extractable P and Mg at 60 cm depth were not significantly different. While, the amount of extractable K and Ca ranged from 30 to 839 mg/kgK and 93 to444 mg/kgCa at 60 cm depth. Fly ash application provided the lowest concentrations of extractable K and Ca with significant differences among treatments. Moreover, extractable S was not significantly different at both 30 and 60 cm depth. Control treatment provided the larger concentration of extractable S and fly ash application caused the lowest amount of extractable S. Moreover, fly ash application showed the lowest concentrations of extractable P, K, Ca and Mg at 30 cm depth with 29, 200, 185 and 68 mg/kg respectively.

Table 1. Nutrients in resin four months after application of fertilizers and soil amendments estimating by Bray II and NH_4OAc extractants.

Treatment	Extractable P (mg/kg)	Extractable K (mg/kg)	Extractable Ca (mg/kg)	Extractable Mg (mg/kg)
	With BrayII	With NH_4OAc pH 7.0		
Samples at 30 cm depth				
Control (NPK)	293	771	1860	398
C + Dolomite	176	783	2709	407
C + Fly Ash	55	228	869	127
Chicken Manure	146	831	1248	191
LSD(P=0.05)	117.83	NS	NS	NS
Samples at 60 cm depth				
Control (NPK)	58	375	1021	167
C + Dolomite	28	1005	1601	323
C + Fly Ash	26	47	549	32
Chicken Manure	44	925	883	211
LSD(P=0.05)	26.73	623.69	952.99	NS

Table 2. Nutrients absorbed by resin four months after application of fertilizers and soil amendments and extracted by 0.5N HCl.

Treatment	Extractable P (mg/kg)	Extractable K (mg/kg)	Extractable Ca (mg/kg)	Extractable Mg (mg/kg)	Extractable S (mg/kg)
	With 0.5N HCl				
Samples at 30 cm depth					
Control (NPK)	74	617	426	164	64
C + Dolomite	46	627	1871	296	54
C + Fly Ash	29	200	185	68	86
Chicken Manure	47	665	742	112	57
LSD(P=0.05)	NS	NS	NS	NS	NS
Samples at 60 cm depth					
Control (NPK)	15	300	278	89	133
C+Dolomite	14	839	444	157	73
C+Fly Ash	27	30	93	39	100
Chiken Manure	14	769	426	107	85
LSD(P=0.05)	NS	480.44	345.43	NS	NS

Conclusion

Nutrients concentration estimated with Bray II and NH_4OAc pH 7.0 than 0.5N HCl extractions showed that nutrients had leached to subsoil and been absorbed by resin. Concentration at 30 cm depth showed in height comparing with 60 cm depth. Control treatment or NPK fertilizer under lychee canopies caused more leaching of nutrients than other treatments. The addition several soil amendments affected leaching of nutrients both at 30 and 60 cm depth. The next experiment should include heavy metals leached.

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Does irrigation prevent phosphorus and sediment loss via wind erosion and benefit surface water quality?

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Abstract

The Mackenzie Basin of New Zealand contains many highly valued and pristine phosphorus (P)-limited lakes. There is a proposal to increase the area of intensive dairying and irrigating pasture in the region. It is accepted that intensive dairying and irrigation of pasture increases P lost by runoff compared to dryland, but in the wind erosion prone Mackenzie Basin, many have hypothesized that irrigation may decrease Aeolian losses and overall, counter any increased losses by runoff. An 18 month study was conducted to determine if wind erosion of P and sediment from sheep-grazed irrigated pasture was less than from dryland. Concentrations and loads of P and sediment were greatest near the soil surface due to saltation of particles, where more P but less sediment was lost from irrigated pasture, but no differences were noted above 1 m. Loads of P and sediment at 5 m, likely to travel the farthest, were low (about 0.058 kg P/ha and 70 kg sediment/ha) and generated mostly in summer when foehn winds coupled with low soil moisture yielded the greatest wind erosion. An example calculation for Lake Tekapo estimated inputs of P to the lake by deposition were small (< 11%) compared to that in the lake or from fluvial or lacustrine sources. The data refutes the hypothesis that irrigated pasture compared to dryland would decrease P loads to the lakes and benefit water quality, but suggests that irrigation of pasture may be beneficial to prevent soil loss by wind erosion.

Key Words

Deposition, water quality, foehn winds, dryland

Introduction

Wind erosion is recognised as an important mechanism for the loss of topsoil and entrained nutrients, including P (Larney *et al.* 1998). Using Cs^{137} techniques, Basher and Webb (1997) measured a loss of 2.2 cm of topsoil between 1953 and 1992 from the Mackenzie Basin in the central South Island of New Zealand. The basin is thought to be prone to wind erosion due to a combination of: sandy soils, often low in organic carbon; frost heave in winter; strong winds and soil moisture deficits in summer; infestations of rabbits leading to bare ground; and treading damage by grazing sheep and cattle (Basher and Webb 1997; Cuff 2001; Floate *et al.* 1994). A recent scoping study by Brown and Harris (2005) looked at the social, economic and environmental impact of irrigating land. While economic and social benefits were evident, potential environmental impact on the Basin's nationally treasured rivers and lakes by nutrients have thus far precluded development. However, Brown and Harris (2005) also note that one spill-over benefit of irrigation is decreased soil loss, via wind erosion, due to better ground cover. Since short-range atmospheric transport has been shown to be a source of P entering oligotrophic lakes (Cole *et al.* 1990), the potential decrease in erosion has also been used as a hypothesis by interested parties that irrigation will not affect water quality. However, no data exists to confirm this. This paper examines wind erosion and deposition rates of P within sheep-grazed irrigated pasture and dryland areas to test this hypothesis.

Methods

Study site

The study sites were located within 1 km of one another at an elevation of 630-680 m above sea level and within a 20 km radius of Lake Tekapo in the upper Waitaki catchment of the Mackenzie Basin. Landuse at the study sites was either dryland pasture (annual rainfall ranged 440-600 mm) or irrigated pasture with 300 mm of additional water supplied via flood irrigation between October and May (provided sufficient water was available for irrigation). Soil at both study sites was mapped as an acidic-weathered Orthic Recent (New Zealand soil classification) Mackenzie sandy loam by Webb (1992). They are usually shallow (commonly < 50 cm deep) and typically have, in the 0-12 cm depth of topsoil, little water holding capacity (~21% v/v), low organic C (~24 g/kg) and N (~1.7 g/kg), and a bulk density of *c.* 0.96 g/cm^3.

Management of the dryland site involved extensive grazing by sheep (1-2 stock units [su]/ha), with P and S applied sparingly every 2-3 years. In contrast, the irrigated sheep site supported about 17 su/ha, and in addition to summer applications of 20 kg P/ha and 30 kg S/ha, up to about 150 kg N/ha is used to boost production during the relatively short growing season.

Sample collection and analyses

Trap units (4) were made according to the design of Li *et al*. (2004) and installed in the middle of each site with at least 1 km in any direction before landuse changed. Trap units collected windblown material at 1 cm above the soil surface, (termed "ground") and airborne dust deposition at 0.5, 1, 2, and 5 m above the soil surface. At each level, traps had duplicate containers (3 L volume and 200 cm^2 surface area) that were open to collect dust. Deionised water (2 L) was added to each trap to assist dust trapping, the solution collected after 21-days, and another 2 L added. Sampling began in March 2008 and stopped in October 2009. Weather stations were installed at the top of each unit to measure wind speed and direction and generate a wind rose (Figure 1).

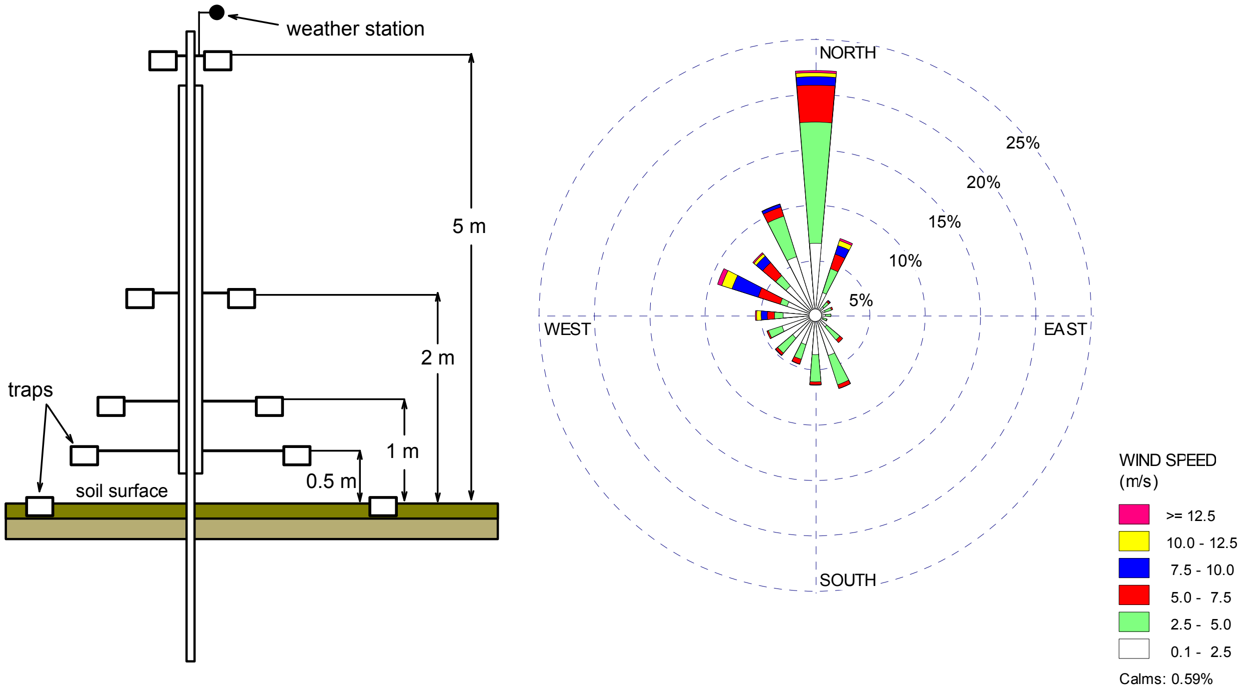

Figure 1. Design of trap units used for the collection of airborne dust (adapted from Li *et al.* 2004) and the resulting wind rose plot for the combined wind speed and direction at both sites during the 18-month study.

Soil samples (0-7.5 cm depth) were taken in November 2008 (mid study) every 2 m along north, south east and west transects away from the trap unit for 10 m and bulked for each trap unit. These samples were air-dried, crushed, sieved (< 2-mm) and analysed for Olsen P. For each water sample, molybdate colorimetry was used to determine total P (hereafter referred to as just P) on a sub-sample that had been first digested with persulphate. Sediment in each sample was determined gravimetrically on a 200-500 mL sub-sample after filtration through a 0.7 µm glass fibre paper.

Results and Discussion

The mean loads of P trapped at up to 1 m above the soil surface were greater for irrigated pasture than for dryland (Table 1). This contrasted with the load of sediment which was greater for dryland than sediment (Table 1). McDowell and Sharpley (2009) found that loads of P tended to increase with sediment deposition, but this was for soils of similar P concentration. In the present study, soil Olsen P concentration of the irrigated pasture < 10 m away from the traps was about 4 times (31 mg Olsen P/L) greater than for dryland. It would appear that the P concentration, and not mass of sediment, controlled the P trapped.

With increasing height, the load of P and sediment tended to decrease (e.g., $\text{P load}_{\text{irrigated}} = 1.22 \times \text{height}^{-0.6}$; R^2=0.98, P< 0.01; Table 1). However, while at 5 m the load of sediment had decreased by 84-92% compared to the load at 0.5 m, P had decreased by only 40-60% over the same distance (Table 1). This may be explained by the well known decrease in P concentration with increasing particle size (Sharpley 1980) coupled with the decrease in particle size with increasing height established at a site 60 km to the north of the present study by McGowan and Sturman (1997). McGowan and Sturman (1997) attributed most of the difference to a change at about 1 m from particles lifted and deposited within a short distance (saltation) to lighter particles that are lifted and remain suspended in airflow (suspension). About 10% of mean hourly wind speeds at the sites (Figure 1) were above the 7.5 m/s necessary for suspension (McGowan 1997).

Table 1. Mean load of phosphorus and sediment deposited at each height within each landuse during the 10-mo study. The least significant difference at $P<0.05$ is given for the interaction between landuse and height.

Landuse/	Height (m)				
constituent	Ground	0.5	1.0	2.0	5.0
Phosphorus (kg/ha)					
Dryland	8.00	0.94	0.54	0.61	0.56
Irrigated	21.76	1.49	0.98	0.86	0.60
LSD_{05} = 0.21					
Sediment (Mg/ha)					
Dryland	1.45	0.92	0.51	0.08	0.07
Irrigated	0.96	0.42	0.21	0.06	0.07
LSD_{05} = 0.19					

During the study, large variations in the concentrations (and loads) of TP and sediment were noted, especially close to the soil surface (Figure 2). Maxima in sediment loads have been attributed to wind erosion, in the absence of precipitation, associated with warm dry and gusty foehn winds from the north-west (McGowan and Ledgard 2005). It would appear that P concentrations and loads follow a similar temporal pattern as sediment. Shoulders either side of the maxima near ground level have been attributed (at least for sediment transport) to the erosion of particles made aerodynamically rough by freeze-thaw cycles in spring and autumn (McGowan 1997).

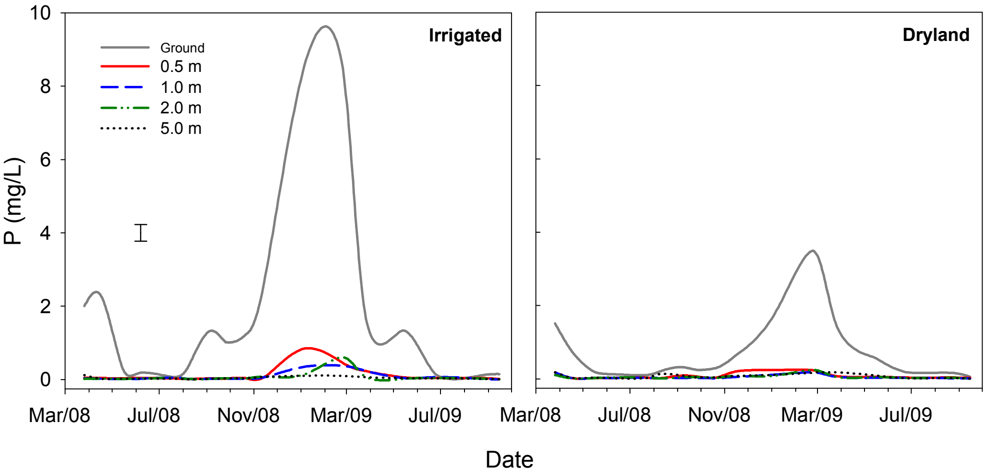

Figure 2. Mean concentration of P for each trap height with time at the irrigated and dryland sites showing seasonal variation. The least significant difference at $P<0.05$ is given for the interaction of landuse and height.

McGowan and Ledgard (2005) calculated the mean soil loss from the study of Basher and Webb (1997) as 6320 kg/ha/yr, but more importantly Basher and Webb (1997) noted that this ranged from zero to a maximum of 8690 kg/ha/yr (as calculated by McGowan and Ledgard 2005). Excluding transport by saltation (likely to be short range), deposition at 2 m and higher was about 60-80 kg/ha (for the 18 months of the study), this agrees well with the 54.3 kg/ha/yr deposition noted at 2 m height by McGowan and Ledgard (2005), but also suggests that mean soil loss is occurring at a rate about 100 times greater than deposition.

Significance for surface water quality

Cole *et al*. (1990) demonstrated that the load of sediment deposited on the surface of Mirror Lake (New Hampshire) had reached a steady state from 25 m onwards that was about one fifth of that deposited near the shore. This may enrich water near the shore with P and sediment due to saltation, but is a moot point given the small proportion of lake shore compared to the surface area of the Mackenzie Basin's lakes. Deposition has been voiced by locals as a significant source of P into the Basin's lakes and therefore an important factor in surface water quality. However, an example calculation shows this not to be true. Lake Tekapo, the closest to the sampling sites has a surface area 9750 ha, a mean volume of 6834×10^6 m^3, and P concentration of 4.7

mg/m^3 (unpublished NIWA data). This yields a load of 32119 kg P in the lake at any one time. In contrast, deposition of 0.38 kg P/ha/yr (annualised from deposition at 5 m height), equates to 3705 kg P/ha/yr deposited. Although comparing well to the <1% of annual stream loads within a mixed landuse catchment in the northeast United States (McDowell and Sharpley 2009), annual deposition to Lake Tekapo would likely account for a maximum of 11% of P in the lake with at least 89% originating from fluvial or lacustrine sources.

Conclusion

The main feature of this work is that when considering all heights, irrigation to support additional pasture growth decreases the wind erosion of sediment compared to dryland, but not P due to greater topsoil P concentrations in the irrigated pasture. Movement of P and sediment increases closer to the soil surface due to saltation of particles, but is unlikely to travel far. Wind erosion, suspending particles > 2 m above the soil surface, which travel further and may have off-site impacts (e.g. affect surface water quality), was found to be similar between landuses. In one example, deposition at 5 m was estimated to be a minor contributor to P loads in Lake Tekapo. This data refutes the hypothesis that increasing land in irrigated pasture compared to dryland pasture would decrease P loads and benefit surface water quality. However, this does not preclude the benefits to decreasing soil erosion by increasing plant cover.

Acknowledgements

Funding for this study was provided by the AgResearch-University of Otago collaboration fund. The assistance of farmers for site access and Sonja Phillip for site maintenance and sample collection is appreciated.

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Effect of a soil moisture retentive material on yield, quality and nutrient accumulation in cowpea and water retention in soil

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Abstract

Cowpea (*Vigna unguinculata (L.)* Walp) is an important legume crop of Maharashtra that is usually grown on residual soil moisture. To increase water use efficiency and reduce irrigation water frequency in cowpea, a soil moisture retentive material "All Purpose Spray Adjuvant-80 (APSA-80™)" was tested and standardized for its effect on yield, growth, nutrient accumulation, saving of irrigation water, and moisture retention at 0-15 and 15-30 cm depths in a lateritic soil of Konkan under cowpea (var. Konkan Sadabahar). Treatment receiving APSA-80™ at 2 mL/L and irrigation at 20 d intervals gave maximum yield of cowpea, retained maximum moisture content, and improved available nutrient status in the studied soil.

Key Words

All Purpose Spray Adjuvant-80, cowpea, irrigation water, moisture retention, yield, nutrient accumulation

Introduction

All Purpose Spray Adjuvant-80™ (APSA-80) is a soil moisture retentive material that possesses an exceptional affinity to absorb and retain large quantities of water (Mukherjee *et al.* 2009). It releases and reabsorbs water repeatedly, which helps in good seed germination, and thus, contributes to increasing crop yields (Anonymous 2007). When it comes in contact with soil it spreads uniformly all over the soil surface, gets absorbed and holds soil particles tightly, thus, reducing the rate of evaporation and improving soil aggregation (Raghavan 2007). The application of APSA-80 can, thus, help to considerably reduce frequency of irrigation and irrigation water requirements of crops, and improve crop water-use efficiency.

Cowpea (*Vigna unguinculata* L. Walp) is an important legume crop with regard to nutrition, as it is a major source of protein with minerals and vitamins. In Maharashtra, cowpea is grown in the *rabi* (winter) season on residual soil water. So we tested APSA-80 in cowpea grown in the lateritic soils of the Konkan with the objectives of evaluating its effect on a) growth, b) yield, and c) nutrient accumulation, d) saving of irrigation water and e) water retention at 0-15 and 15-30 cm depths.

Methods

We conducted a feeler pot culture trial in 2008 using RBD and three replications to test the efficacy of APSA-80 (manufactured by Amway) as a soil moisture retainer for lateritic soils in cowpea (var. Konkan Sadabahar). The soil was brought to saturation and tensiometer readings were recorded against lapse of time for 28 d to measure soil moisture depletion. Treatments included irrigation at 10d intervals (control) (T_1), irrigation at10 d intervals with polyethylene mulch (PE) mulch (T_2), irrigation at 20 d intervals with APSA-80™ (1 mL/L) (T_3), irrigation at 20 d intervals with PE mulch and APSA-80 (1 mL/L) (T_4), irrigation at 20 d intervals and APSA-80™ (2 mL/L) (T_5), irrigation at 20 d interval with PE mulch and APSA-80™ (2 mL/L) (T_6), irrigation at 20 d intervals and APSA-80™ (3 mL/L) (T_7), and irrigation at 20 d intervals with PE and APSA-80™ (3 mL/L) (T_8). Our university recommended macronutrient application should be made with 25:50:0 N:P_2O_5:K_2O.

Results

Crop growth and yield contributing parameters, *viz.,* number of leaflets, primary branches, height of plants, no. of pods and 1000-seed weight, total nutrient uptake, and seed yield of cowpea were improved significantly with the application of APSA-80 alone, and in combination with and without polyethylene mulch when compared with control. The application of APSA-80™ at 2 mL/L (T_5) showed marked improvement in all the above characters over application of irrigation at 10 d interval without and with mulch i.e. (T_1 & T_2). Treatment T_5 registered the highest grain yield (15.5 q/ha) (Table 1), nutrient uptake, and water holding capacity of the studied soil. The use of polyethylene mulch in combination with APSA-80 in different quantities increased the stover yield of cowpea in comparison with the application of APSA-80 alone (Table 1). However, application of APSA-80 alone responded more favorably towards the availability of the nutrients at the harvest of the crop (Table 2).

Table 1. Effect of All Purpose Spray Adjuvant-80 (APSA-80™) on grain and stover yield of cowpea.

Tr. No.	Treatments	Yield (q/ha) and % increase over control (in parenthesis)	
		Grain	Stover
T_1	Control (Irrigation at10 d intervals)	10.23	31.5
T_2	T_1 + polyethylene mulch	11.0 (7.6)	41.2 (30.7)
T_3	Irrigation at 20 d intervals + APSA-80 at 1 mL/L	10.2 (6.0)	32.4 (3.0)
T_4	T_3 + polyethylene mulch	12.5 (22)	40.4 (28.3)
T_5	Irrigation at 20 d interval+ APSA-80 at 2 mL/L	15.5 (51.7)	37.13 (17.87)
T_6	T_5 + polyethylene mulch	11.3 (10.3)	39.4 (25.0)
T_7	Irrigation at 20 d interval+ APSA-80 at 3 mL/L	12.5 (22.2)	35.3 (11.9)
T_8	T_7 + polyethylene mulch	12.2 (19.3)	38.5 (22.3)
	Mean	12.0	37.0
	SEm ±	0.4	0.4
	CD (P=0.05)	1.4	1.2

Table 2. Effect of All Purpose Spray Adjuvant-80 (APSA-80™) on availability of macronutrients at harvest of cowpea.

Tr. No.	Treatments	Ava. N (kg/ha)	Ava. P_2O_5 (kg/ha)	Ava. K_2O (kg/ha)
T_1	Control (Irrigation at10 d intervals)	338.8	10.9	213.5
T_2	T_1 + polyethylene mulch	333.5	12.1	218.2
T_3	Irrigation at 20 d intervals + APSA-80 at 1 mL/L	327.3	12.5	221.9
T_4	T_3 + polyethylene mulch	325.2	13.1	223.5
T_5	Irrigation at 20 d interval+ APSA-80 at 2 mL/L	312.1	13.7	238.1
T_6	T_5 + polyethylene mulch	314.6	13.6	233.9
T_7	Irrigation at 20 d interval+ APSA-80 at 3 mL/L	316.8	13.6	228.1
T_8	T_7 + polyethylene mulch	322.1	13.4	225.1
	Mean	323.8	12.8	225.3
	SEm ±	0.66	0.60	0.005
	CD (P=0.05)	2.00	NS	0.016

Conclusion

Treatment receiving APSA-80 at 2 mL/L and irrigation at 20 d intervals gave maximum yields of cowpea, retained maximum water content, and improved available nutrient status of the studied soil.

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Effect of subsurface drainage for multiple land use in sloping paddy fields

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Abstract

Subsurface drainage improves the productivity of poorly drained soils by lowering the water table, providing greater soil aeration, and enabling faster soil drying and improving root zone soil layer condition. The lower portion of sloping paddy fields normally contains excessive moisture and the water table is higher caused by the inflow of groundwater from the upper part of the field resulting in non-uniform water content distribution. The purpose of this study is to monitor on-farm water table fluctuations and to evaluate the effect of drainage in the soil and its relation to soybean yield. Four drainage methods namely open ditch, vinyl barrier, tile drainage and tube bundle were installed within 1-m position from the lower edge of the upper embankment of sloping alluvial paddy fields. The tile drainage method drained the field faster as compared to the other drainage methods. Results also revealed that the subsurface drainage system can increase crop yield and the overall economic productivity of the soil.

Key Words

Subsurface drainage, moisture stress index, soybean, water table level, paddy field.

Introduction

Subsurface drainage has been widely used in developed countries and by mid-1980s, it was started to be recognized as a solution to water logging and salinity problems in irrigated areas of the developing world. The main reason of using subsurface drainage in paddy field is to improve the soil and create more conducive working conditions for the use of farm machinery especially for large scale paddy plot farming as well as upland crop farming in paddy field (Ogino and Murashima 1993). There are considerable areas of wet paddy fields in Korea that requires improvement of its drainage system. It is well established that one of the most widely accepted methods of improving drainage system in wet fields is subsurface drainage (Lee and Kim 1997). In the late 1980s, the Korean government has encouraged the use of surface drainage for sustainable farming of paddy field. The total area of drained wetland is 170,000 ha or equivalent to 13.1 % of the total area of paddy fields in Korea (Korea Rural Community and Agriculture Corporation 2008). Paddy fields in Korea are particularity different from those in the European countries and America in that they drain excess soil water from shallow surface soil layer. Especially, in alluvial sloping paddy fields, upland crops can be damaged by either rainfall or capillary rise of the water table caused by percolating water beneath the upper fields during summertime rainy season causing variations in soil moisture even in identical fields with curved parallel terracing and contour-lined layout in sloping area where the length of short side is relatively short.

Drainage systems are designed to alter field hydrology by removing excess water from water logged soil. The American Society of Agricultural and Biological Engineers (ASABE 2008) provided scientific criteria from which guidelines are now available to determine the necessity for drain spacing which varies a 7-15 m, with 10 m being a popular distance and trencher depth is about 50 cm and width range from 20 cm to 35 cm depending on the trencher used and diameter of the drain pipe. Drainage improves farm productivity and net returns by adding productive areas without extending farm boundaries. Yield increases of between 10-25 % can be expected depending upon the initial drainage status of the land.

Methods

Site description

Experiment were carried at four poly drained paddy fields located at Oesan-ri, Buk-myeon, Changwon-si out in alluvial slopping paddy fields (35˚22 N, 128˚35 E). The size of standard field plot is 20 m ×80 m; one shot side faces a farm drain. The soil was Jisan series which is a member of the fine loamy, mixed, mesic family of Fluvaquentic Endoaquepts (low humic-gley soils) developed from weakly stratified local alluvial materials in gently sloping narrow valley alluvium and on alluvial fans derived from granite, andesit porphyry and similar soil materials. These soils have moderately thick dark grayish brown loamy Ap horizons and very thick grayish brown light loam cambic Bg horizons with white colored ferrous carbonate ($FeCO_3$) mottles. The Cg horizons are gray or dark bluish gray sandy loam with few white ferrous carbonate ($FeCO_3$) mottles.

Table 1. Selected soil physical properties of the research site. The site is composed primarily of Jisan series(fine loamy, mixed, mesic family of Fluvaquentic Endoaquepts).

Horizon	Depth (cm)	Bulk density (Mg/m^3)	Three phases (%)			Porosity (%)	Textural Class	Water holding capacity (%)	
			Solid	Water	Air			-33KPa	-1500KPa
Ap1	0~10	1.18	44.5	40.2	15.3	55.5	loam	41.4	21.7
Ap2	10~20	1.55	58.6	25.9	15.5	41.4	loam	26.9	11.0
Ag	20~24	1.62	61.2	24.1	14.6	38.8	loam	21.6	9.9
Bg	24~35	1.60	60.3	22.3	17.4	39.7	Sandy loam	18.5	8.1
BCg	35+	1.60	60.4	25.0	14.5	39.6	Sandy loam	19.3	9.0

Drainage system

The drainage system is designed to remove excess water from the soil quickly enougth to minimize crop stress thru at 1-m position of beneath upper field bank using four kinds drainage methods, namely open ditch, vinyl barrier, tile drainage, and tube bundle (Figure 1). The field experiment had been installed at pooly drained paddy field in 2007. The polythene (HDPE) corrugated pipes wrapped with poly wave nets tile drainage were placed in trenches measuring 50 cm wide and 60 cm deep. The pipes were then encased in a mixture of gravel to a circumference thickness of 10-15 cm. then the trenches were filled with dug earth to the orignal level. These pipes eventually drain through the wall into the open perimeter ditch (Figure 1). The drainage system investigation was laid out in a randomised complete block design with two replications.

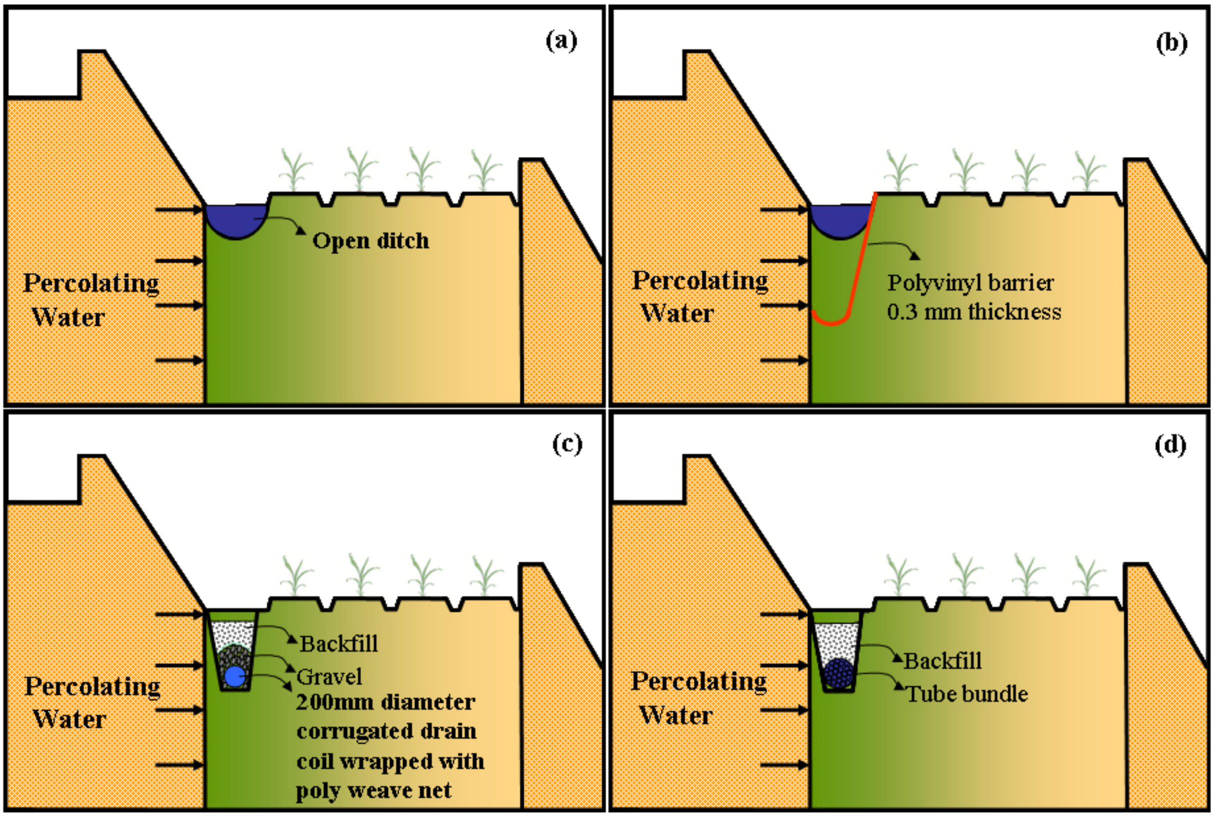

Figure 1. Schematic showing various drainage system. (a) Open ditch (b) Vinyl barrier (c) tile drainage (d) Tube bundle.

Water table monitoring and soil moisture measurements

The measurement of soil moisture levels after drainage, which are used to determine the soil bearing capacity were made at 3, 10 and 15-m positions from the edge of the upstream bank of the field where the each drainage type was constructed. During the same period of soil moisture measurement, the water table levels were monitored from 150-cm long small tube wells made from 50-mm poly vinylchloride (PVC) pipes.

Waterlogging was assessed over the season using the water table levels from the tube wells placed every 60-m in a grid pattern and by calculating the daily sum of excess water in the profile above 30 cm soil depth (SEW_{30}) for each deep well (McFarlane *et al.* 1989). SEW_{30} values are dependent on both surface and subsurface drainage. In most cases several alternative combinations of surface and subsurface drainage can be used to satisfy a given SED_{30} limit. Drainage requirements for trafficability during the seedbed perparation periods were about the same for three locations (Skaggs 1980). The SEW_{30} was calculated using the expression

$$SEW_{30} = \sum_{i=1}^{n} (30 - x_i)$$

where x_i is the water table depth on the i^{th} day, with $i = 1$ being the first day and n the number of days in the growing season(Setter and Waters 2003, McFarlane *et al.* 1989).

Results

The infiltration rate of 20.87 cm/hr recorded in the subsurface drained fields was substantially higher than the 0.15 cm/hr obtained in the field with open ditch. The decrease in moisture within the soil profile and the attainment of the maximum water-holding capacity after the occurrence of rainfall is faster in the tile drainage than in the open ditch drainage method (Figure 2). The sum of excess water days (SWD_{30}), used to represent the moisture stress index, was lowest in the tile drainage method at 31 days compared with the open ditch drainage method at 135 days(Table 2). The soil water content spatial variability was highest in the vinyl barrier method 270.8 m, followed by subsurface method 223.2m, tube bundle 140.1m and open ditch drainage method 64.6m. The effectiveness drainage on tile drainage method more cleared up than the other drainage methods. It was showed that the tile drainage system had helped in increasing crop yields as well as improving soil productivity and consequently total economic value of such a production (Figure 2).

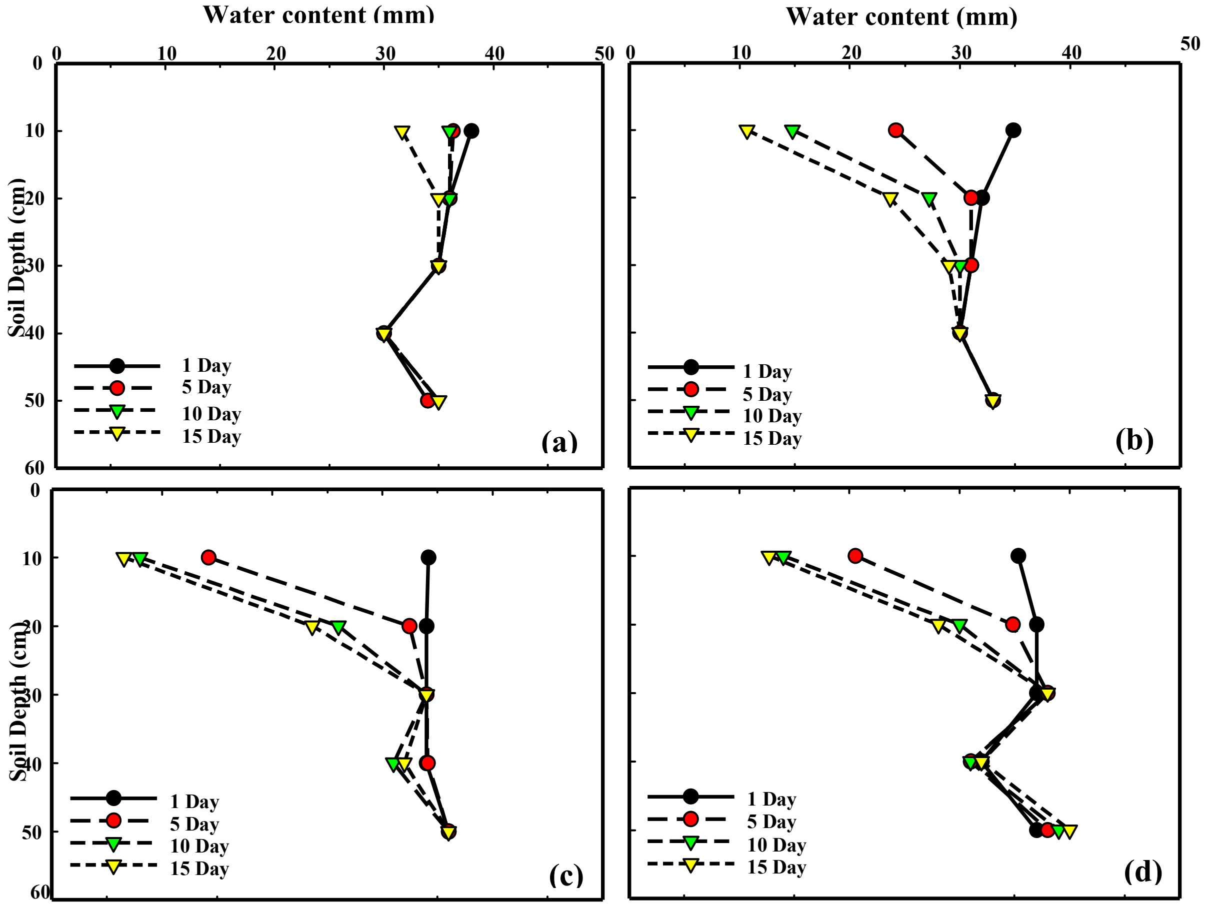

Figure 2. Soil water content of soil horizon after rainfall. (a) Open ditch (b) Vinyl barrier (c) Tile drainage (d) Tube bundle.

Table 2. Comparison of various stress index factors in different drainage type.

Type of Drainage	SEW_{30}[A] (> 30mm/hr)	Average Water content (mm)	Duration time Excess Water (> 30mm/hr)	Decrease of ground water table (cm/hr)	SED_{30}[B]
Open ditch	1,270	30.10	340	0.28	135
Vinyl barrier	165	20.03	52	1.37	125
Tile drainage	100	12.15	48	9.50	31
Tube bundle	114	12.60	51	7.37	100

[A] SEW_{30}: Sum of Excess Water Depth, [b] SED_{30}: Sum of Excess Water Day.

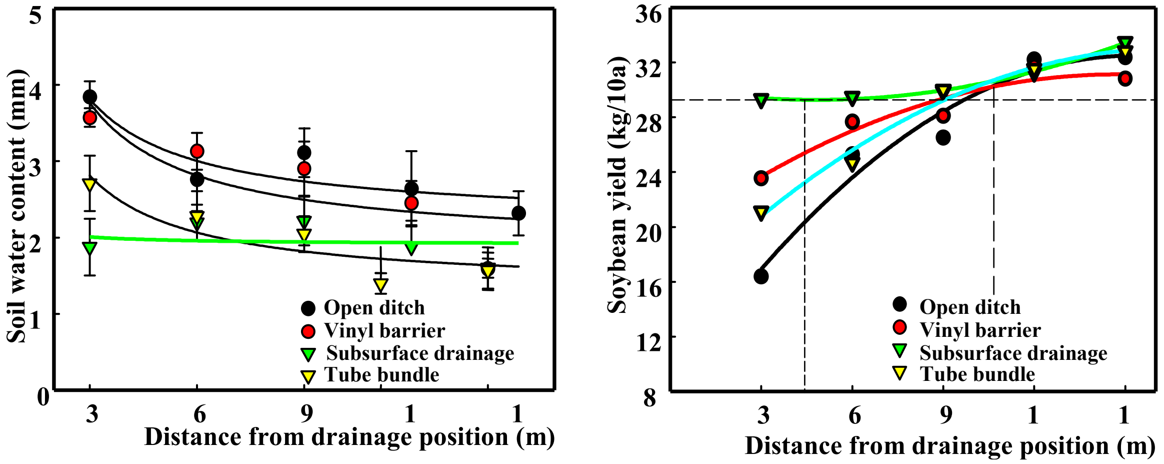

Figure 3. Comparison of soil moisture content and soybean yield at drainage installed position by drainage method.

Conclusion

The Infiltration rate showed high tendency to tile drainage method about 20.87 cm/hr than in open ditch method 0.15 cm/hr. The decrement of the moisture of the depth of the remaining water appeared the change of the soil moisture on tile drainage than a open ditch method greatly based on reach the maximum water holding capacity after rain fall according to the overdue days. Sum of excess water day (SWD_{30}) used to represent the moisture stress index was most low on the tile drainage 31 days compared with the open ditch 135 days. The tile drainage method drained the field faster as compared to the other drainage methods. Results also revealed that the subsurface drainage system can increase crop yield and the overall economic productivity of the soil. Yield of soybean at subsurface drainage treatment were higher than yield from the open ditch drainage. Soybean yield and soil water content is uniform distance from drainage position.

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Evaluation and estimation of soil erodibility by different techniques and their relationships

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Abstract

Direct measurement of soil erodibility, resistance offered by the soil to both detachment and transport processes, is not only costly but time consuming also. So, efforts have been made to predict it from the soil physical properties. To evaluate soil erodibility under different land uses using natural and simulated rainfall and to estimate soil erodibility by nomographic (Wischmeier *et al.* 1971) and fuzzy logic method (Torri *et al.* 1997), a field experiment was conducted both under natural and simulated rainfall conditions under four land uses viz. barren, cultivated, grassland and forest in the submontaneous tract of Punjab (India). Measured soil erodibility (K) values varied from 0.33 to 0.67 under natural rainfall conditions and from 0.23 to 0.40 under simulated rainfall conditions. Values of the soil erodibility factor estimated by nomograph and FUZKBAS program were very low as compared to the observed values. The trends were also in contrast to these observed values of soil erodibility under simulated and natural rainfall conditions.

Key Words

Soil erosion, soil aggregation, soil texture, rainfall simulator, universal soil loss equation

Introduction

Soil erosion depends not only on rainfall erosivity but also on the soil's resistance to erosion, which is usually measured as the soil erodibility factor K. The measurement of K can be done using Universal Soil Loss Equation (USLE) given by Wischmeier and Smith (1978) by knowing other factors of the equation using natural or simulated rainfall experimentation, but this process is costly and time consuming. Wischmeier *et al*. (1971) gave empirical nomograph for estimating erodibility from basic soil properties. Fuzzy logic based program FUZKBAS was also given by Torri *et al*. (1997) to obtain K values. Present study was planned to study the interrelationship between different methods of estimating soil erodibility.

Methods

Experimental sites

Field experiment was done in ecologically fragile zone of lower Himalayas in North-west India, the Shiwalik system. Four sites of the sub-montaneous region of Punjab i.e. Ballowal Saunkri – I, Ballowal Saunkri – II, Kokowal Majari and Saleran differing in soil texture and other soil properties were selected with four land uses i.e. barren, cultivated, grassland and forest at each location.

Experimental details

To determine soil erodibility, field experiment was conducted at two locations i.e. Ballowal Saunkhri-I and Ballowal Saunkhri-II under natural rainfall conditions and at four locations i.e. Ballowal Saunkhri-I, Ballowal Saunkhri-II, Kokowal Majari and Saleran under simulated rainfall conditions under four land uses with three replications each. Under natural rainfall conditions plots measuring 5 m x 1.5 m were prepared and the average slope of the plots was maintained at 4 percent. For simulated rainfall experiment using micro-sprinkler based rainfall simulator the plot size kept was 2.5 m x 1.0 m with 4 percent slope. Soil erodibility was evaluated using Universal Soil Loss Equation (USLE) as described in Singh and Khera (2009).

Soil analysis

Standards methods were employed to analyze the collected soil samples for water stable aggregates, mean weight diameter, particle size analysis, steady state infiltration rate, saturated hydraulic conductivity and soil organic carbon.

Nomographic estimation of soil erodibility

The modified version of nomographic expression given by Wischmeier *et al.* (1971) for estimating K in SI units (t ha hr / ha MJ mm) as given by Rosewell (1993) was used.

$K = 2.77\ M^{1.14}(10^{-7})(12-\alpha) + 4.28(10^{-3})(\beta-2) + 3.29(10^{-3})(\gamma-3)$

Where, M = (% silt+% Very fine sand).(100-% clay), α = Organic matter (%), β = structure code and γ = permeability rating.

Fuzzy logic based estimation of soil erodibility

Fuzzy logic based program FUZKBAS (Torri *et a.l* 1997) was used to estimate K distribution as a function of the decimal logarithm of the geometric mean particle size (Dg), the clay fraction and organic matter content.

Results

Observed soil erodibility under natural rainfall conditions

Under natural rainfall conditions, soil erodibility values based on EI_{30} index varied from 0.35 to 0.67 (Table 1). The erodibility values were significantly higher at Ballowal Saunkhri-II (0.54) than that at Ballowal Saunkhri-I (0.45), under all land uses. The barren soils were having highest erodibility value (0.62) followed by cultivated (0.55), grassland (0.45) and forest (0.39) soils.

Observed soil erodibility under simulated rainfall conditions

Under simulated rainfall conditions, Ballowal Saunkhri-II location was having highest soil erodibility (0.34) whereas Kokowal Majari was having lowest values of soil erodibility (0.25). Among different land uses, it was observed in the order of barren (0.34) > cultivated (0.30) > grassland (0.29) > forest (0.25) land use (Table 2).

Nomographic estimation of soil erodibility

The soil erodibility factor (K) estimated using nomograph varied from 0.14 to 0.46 (Table 3). As compared to observed K values, the values obtained using nomograph were low. Among different locations, significantly highest K values were obtained for Kokowal Majari (0.43) and lowest for Ballowal Saunkhri-II (0.15).

Fuzzy logic based estimation of soil erodibility

The maximum membership K values were 0.15, 0.14, 0.33 and 0.14 for Ballowal Saunkhri-I, Ballowal Saunkhri-II, Kokowal Majari and Saleran locations (Table 4). Among different land uses the fuzzy logic K values were 0.15, 0.16, 0.20 and 0.25 for barren cultivated, grassland and forest soils respectively.

Interrelationship among soil erodibility values determined using different methods

Measured soil erodibility varies from 0.35 to 0.67 for natural rainfall conditions and from 0.23 to 0.40 for simulated rainfall conditions and it was in the order of Kokowal majari < Ballowal Saunkhri-I = Saleran < Ballowal Saunkhri - II. Among different land uses, measured soil erodibility both under natural and simulated rainfall conditions was in the order of barren > cultivated > grassland > forest soils. Soil erodibility estimated using nomograph was Ballowal saunkhri – II < Saleran < Ballowal Saunkhri – I < Kokowal Majari, which was in contrast to the observed values of soil erodibility (Figure 1).

Values of the erodibility factor estimated by FUZKBAS program were very low (0.10 to 0.36) as compared to the observed values. These were also in contrast to the observed values of soil erodibility, which were 0.31, 0.34, 0.25 and 0.31 for Ballowal Saunkhri-I, Ballowal Saunkhri-II, Kokowal Majari and Saleran locations under simulated rainfall conditions. The highest values were obtained for Kokowal Majari using FUZKBAS whereas observed values for this location were lowest. This model gave highest values of soil erodibility under forest land use in contrast to observed K values under natural and simulated rainfall conditions. The correlation coefficient between observed K and nomograph K was -0.59, for observed K and FUZKBAS K it was -0.73 and for nomograph K and FUZKBAS K it was 0.92.

Table 1. Soil erodibility factor K (customary units) at two locations under four land uses for natural rainfall conditions.

Location	Barren	Cultivated	Grassland	Forest	Mean
Ballowal Saunkhri – I	0.56	0.49	0.41	0.35	0.45
Ballowal Saunkhri – II	0.67	0.60	0.48	0.42	0.54
Mean	0.62	0.55	0.45	0.39	
CD (0.05) Location = 0.01, Land use = 0.02, Location X Land use = 0.02					

K in SI units = K in customary units x 0.1317

Table 2. Soil erodibility factor K (customary units) under four land uses under simulated rainfall conditions.

Location	Barren	Cultivated	Grassland	Forest	Mean
Ballowal Saunkhri-I	0.39	0.28	0.30	0.26	0.31
Ballowal Saunkhri-II	0.40	0.36	0.33	0.27	0.34
Kokowal Majari	0.27	0.25	0.24	0.23	0.25
Saleran	0.33	0.31	0.30	0.26	0.31
Mean	0.34	0.30	0.29	0.25	
CD (0.05) Location = 0.02, Land use = 0.02, Location X Land Use = 0.03					

K in SI units = K in customary units x 0.1317

Table 3. Nomographic estimation of soil erodibility factor K (customary units) at four locations under four land uses.

Location	Barren	Cultivated	Grassland	Forest	Mean
Ballowal Saunkhri – I	0.20	0.34	0.24	0.17	0.24
Ballowal Saunkhri – II	0.14	0.13	0.20	0.14	0.15
Kokowal Majari	0.46	0.43	0.43	0.38	0.43
Saleran	0.20	0.21	0.15	0.17	0.18
Mean	0.26	0.29	0.25	0.20	
CD (0.05) Location = 0.03, Land use = 0.03, Location x Land Use = 0.06					

K in SI units = K in customary units x 0.1317

Table 4. Fuzzy logic based estimation of soil erodibility factor K at four locations under four land uses.

Location	Barren	Cultivated	Grassland	Forest	Mean
Ballowal Saunkhri – I	0.10	0.12	0.10	0.27	0.15
Ballowal Saunkhri – II	0.10	0.10	0.22	0.13	0.14
Kokowal Majari	0.30	0.30	0.36	0.34	0.33
Saleran	0.10	0.10	0.10	0.27	0.14
Mean	0.15	0.16	0.20	0.25	
CD (0.05) Location = 0.003, Land use = 0.004, Location x Land Use = 0.006					

K in SI units = K in customary units x 0.1317

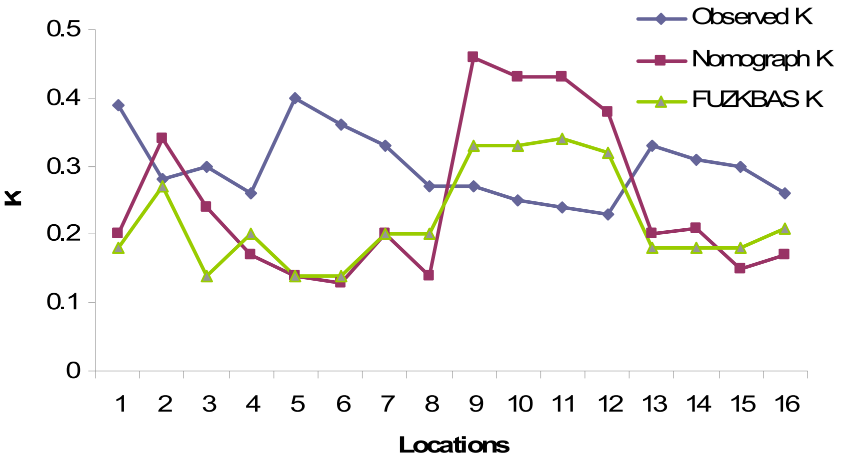

Figure 1. Soil erodibility values determined using different methods.

Conclusion

The nomograph and fuzzy logic method estimation of soil erodibility are not applicable under studied conditions. The reason may be that these methods are based on the data sets or experiments which were not conducted under Indian conditions and being empirical in nature these cannot be extrapolated to other locations. Nomographic method can be modified to use it under Indian conditions (Singh and Khera 2009).

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Hairy vetch and rye as cover crops to reduce soil erosion from sloped land in highland agriculture

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Abstract

Effect of cover crop on reducing soil loss from a highland experimental farm during the cropping period from 2005 to 2008 was examined. The amount of soil loss was 1.6 tons/ha from the bare plot, while that from the plots with cover crops, rye or hairy vetch, were 0.4 and 0.7 MT/ha/yr. Biomass of rye and hairy vetch before incorporation were 27.5 and 31.4 MT/ha/yr, respectively, while that of the non-cover crop control plot was 12.6 MT/ha/yr. It implied that 4.9 kg to 9.9 MT/ha of dry matter could be supplied as covering organic material for main crops in growing season. When these cover crops were used as green manure by inversion into the soil or covering after cutting, the Chinese cabbage of the hairy vetch plot had yields that were over 2 times higher, from 35.9 to 45.2 MT/ha, than the control plot with yields from 16.0 to 20.0 MT/ha, and the yields of rye ranged from 17.7 to 22.4 MT/ha. In the case of radish, the yields from the hairy vetch plot and the rye plot were from 10.2 to 11.5 MT/ha, and 57.7 to 69.3 MT/ha, compared with the yield of control plot which ranged from 43.5 to 45.1 MT/ha. In conclusion, cultivation of cover crops such as rye and hairy vetch in fallow period was a very effective method to reduce soil loss and increase soil fertility.

Key Words

Cover crop, green manure, hairy vetch, rye, highland agriculture.

Introduction

In highland agriculture in Gangwon Province in Korea, about 70% of the farm lands are located on over 7% slope, where the erosion potential is high. Growing season of crops such as Chinese cabbage, radish and potato in this area is 60 to 120 days a year, and the rest of the time the soil was left bare condition susceptible to soil erosion. Cho (1999) pointed out that effective soil depth of highland in this province was range 10 to 60 cm which is quite shallow for most crops, and lefts bare during non-cropping period. Severe erosion occurs with poor soil coverage during fallow periods. Cover crops can provide protection during such periods left bare. Baver *et al.* (1972) and Wischmeier and smith (1978) reported that maintaining of reasonable cropping system reduced erosion by wind, snow melting and rainfall. Plant residues reduce the impact of raindrops that otherwise would detach soil particles and make them prone to erosion (Laflen *et al.* 1979). Surface runoff is slowed by the cover, allowing improved moisture infiltration. And the root system helps stabilize the soil by infiltrating the profile and holding it in place. Cover crops can add organic matter to the soil which improves soil tilth and productivity. Michell and Teel (1977) and Ebelhar *et al.* (1984) who reported that cultivation of hairy vetch as cover crop and green manure could reduce use of chemical fertilizers. The objectives of the study were to find out the effect of cover crop on reduction of soil loss, and increasing organic matter and crop productivities in highland area.

Methods

A field experiment was conducted from 2005-08 on a farm with the 10% slope located in Hoenggye-Ri, Daegwallyeong-Myun, Pyeongchang-Gun, Gangwon-Do, at a 750 m elevation. Cover crops, hairy vetch and rye were seeded in early September, and the main crops, Chinese cabbages and radishes were seeded or planted at the end of June of the following year. The experimental design was a randomized split-plot with 3 replicates, with cover crop species of bare, rye (*Secale cereal* L.), hairy vetch(*Vicia villosa* Roth) as the main plots. The sub treatments included application methods of residues to the soil by incorporating soil and surface covering after cut. Rye and hairy vetch were seeded 200 kg and 50 kg/ha. Covering rate was checked once a month and fresh, and dry matter amounts were measured from 1 m^2 of every plot before incorporation. The plots with 3 X 10 m^2 were set for all plots and total runoff and eroded materials were collected with the 400 L collection tanks. Collected eroded materials were sampled after each rain event. Incorporation of cover crop residues was conducted at 15 and 5 days before seeding or planting of main crops, respectively. Surface covering was conducted at 10 days before seeding or planting. No additional fertilizers were used on the plots. Yields of radish and Chinese cabbage were measured at harvest time. The plants were dried and analyzed for inorganic components (T-N, P_2O_5, K_2O etc.). Cultural methods for growing radish and Chinese cabbage and analytic methods for soil and plant elements followed Standard RDA methods. And statistical analyses were conducted using analysis of variance (ANOVA) procedures of Windows SAS Version 9.0 (SAS Institute, Cary, NC).

Results

The total amount of soil loss from the hairy vetch and rye cover crop plots during fallow period were 7 and 4 MT/ha, compared with bare plot of 16 MT/ha (Figure 1 and Table 1). The results indicated that 56 to 75 percents of soil loss could be reduced by cover crops. In the following year, dry matter of hairy vetch and rye plots were 4.94 and 9.90 MT/ha, compared with 2.29 MT/ha of the bare control plot. There were 216% and 432% increasing effect of organic matter in hairy vetch and rye respectively, compared with the bare control plot. The organic matter supply was higher in the rye plot. The hairy vetch, as a legume has high nutrient contents in itself, could supply 210 kg N, 44 kg P_2O_5 and 114 kg K_2O/ha to the following main crop as calculated from the inorganic contents of Table 1.

Rye Hairy vetch Bare

Figure 1. Effect of soil cover of rye and hairy vetch on winter period.

Table 1. Amount of biomass, dry matter, nutrient component, and soil loss from cover crop plots.

Cover crops	Biomass (kg/ha)	Dry matter (kg/ha)	Inorganic component (%)			Soil loss (MT/ha)
			T-N	P_2O_5	K_2O	
Hairy vetch	31,420	4,940	4.2	0.9	2.3	7
Rye	27,520	9,900	0.9	0.3	1.1	4
Bare	12,610	2,290	1.8	0.4	1.5	16

The yield of Chinese cabbage and hairy vetch plots was over 2 times higher than the control, ranging from 35.9 to 45.2 MT/ha versus the control plot at 16.0 to 20.0 MT/ha. The yield from the rye plots were 17.7-22.4 MT/ha. In the case of radish, the yield of hairy vetch and rye plots were 102.1-115.1 MT/ha and 57.7-69.3 MT/ha, compared with the bare plot at 43.5-45.1 MT/ha (Table 2).

Conclusion

Cover crop such as hairy vetch or rye resulted in reduction of soil loss from 56 to 75%. Incorporation in the soil of these cover crops showed over 2 to 2.5 times the nutrient supply. Therefore, using hairy vetch and rye during fallow period as cover crop showed large potential to decrease soil loss and increase fertility of soil for highland agriculture. Cover crops in highland can provide environmental benefits that make cover crops suitable for enhancing soil conservation and recovery of soil fertility.

Table 2. Yields and inorganic components of Chinese cabbage and radish in incorporation of cover crops

Cover crops	Incorporation Method (I.M)	Chinese cabbage				Radish			
		Yield (MT/ha)	Inorganic component (%)			Yield (kg 10/a)	Inorganic component (%)		
			T-N	P_2O_5	K_2O		T-N	P_2O_5	K_2O
Hairy vetch	Inversion	39.5	8.2	3.6	5.8	115.1	13.7	10.6	19.6
	Covering	45.2	7.5	2.9	4.5	102.1	12.9	8.3	17.2
Rye	Inversion	22.5	4.3	2.2	3.4	69.3	7.2	6.5	12.3
	Covering	17.7	4.1	1.8	2.6	57.7	6.7	5.0	10.4
Bare	Inversion	20.0	4.0	21	3.1	45.1	5.1	3.9	8.7
	Covering	16.0	3.5	1.6	2.5	43.5	5.4	3.6	7.3
Cover crop (A)		**				**			
I.M. (B)		ns				ns			
A*B		ns				ns			

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Impact of land use and hydrology on the soil characteristics and productivity in highland agriculture with watershed approach

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Abstract

A multidisciplinary long-term study, with seven land use systems, was undertaken to monitor the impact of land use and hydrological regimes on the changes in soil properties and crop productivity. Results showed that maximum increase of available P was found in horticulture land use, where it increased from 2.7 (initial status) to 24.9 mg P/kg soil, followed closely by agri-horti-silvi-pastoral (21.4 mg P/kg soil), agriculture (17.6 mg/kg soil) and livestock based (16.2 mg/kg soil). The build-up of available K showed a similar trend, except that highest available K in the soil was found for shifting cultivation land use during first two years of study. Continuous vegetation cover and tree plantation had an ameliorating effect in the soil and considerably improved soil fertility and crop productivity. On an average, 0.09 to 1.41 t sediment yield/ha and more than 90% of rainwater was retained *in-situ* in new land use systems as compared to 36.21 t sediment and 66.3% rainwater retention in shifting cultivation. Due to more infiltration of rainwater in the soil because of good vegetation cover, the runoff has considerably reduced, resulting in low flows to river channels and reduced sediment load in the runoff.

Key Words

Land use, hydrology, soil characteristics, highland agriculture, productivity, watershed

Introduction

The north-eastern region of India, comprising seven states, is inhabited by various tribes. It receives 2450 mm as average annual rainfall, but its indiscriminate use and mismanagement has rendered the region in a fragile state. The region is predominantly hilly. Shifting cultivation is practised in 3869 km^2 area, annually, however, the total affected area is 14,660 km^2. It has resulted in a decline in soil fertility and huge soil erosion rates in the hills and silting of river beds and floods in the plains. Land use change and its hydrological consequences have received considerable attention in hydrology. The space-time distribution of soil moisture provides a crucial link between hydrological and biophysical processes through its controlling influence on transpiration, runoff generation, carbon assimilation and water absorption by plants. It is often suggested that it is important to include changes in hydrological fluxes and soil properties in response to land use change. Hydrologists have considerable interest in land use change and its hydrological consequences, both from the perspective of field monitoring (Bosch & Hewlett 1982) and from a modelling perspective (Niehoff 2002). Studies have shown significant effects of land use change on hydrological fluxes. It is a common practice to vary only the spatial distribution of the vegetation cover when modelling the effect of land use change (Fohrer *et al.* 2002). However, in the long term, the land use change will also have an effect on soil physical properties. Several studies on tropical soils reveal an increase in bulk density when forest land is converted to pasture or crop land (Murty *et al.* 2002). The fast growing population has put pressure on the food production base and to satisfy their needs, the people have mismanaged and misused water resources (Sharma 2003; Sharma and Sharma 2008). Due to anthropogenic and natural factors like prevalence of shifting cultivation, land tenure system, free range grazing, deforestation and heavy rainfall; there has been large-scale land and environmental degradation in the region. A multidisciplinary long-term study was undertaken to monitor the impact of land use and hydrological regimes on the changes in soil properties and crop productivity as well as extent of the soil and nutrient erosion due to runoff.

Methods

To evolve eco-friendly, viable and sustainable land use systems, a multi-disciplinary, long-term study was undertaken with different land use systems (Table 1) to monitor their comparative efficacy with regard to *in-situ* retention of rain water, water yield as runoff, effect on soil constituents, loss of soil from different watersheds as well as influence of livestock on soil properties. The livestock included cows, pigs, rabbits and goats. Sediment yield from erosion was evaluated through representative gauges installed at the exit point of each land use watershed. The runoff samples, whenever it occurred, were collected in a permanently fixed small structure and representative samples were drawn for the soil content and analysis of nutrient elements. A part of the runoff samples was dried to determine the sediment yield. The watersheds slope varied from 32% to 41% and soil and water conservation measures followed were contour bunds, trenches, bench terraces, half-moon terraces and grassed water-ways (Table 1). The monitoring gauges were installed at the exit point of each watershed and the observations were recorded during different years under various rainfall regimes. The initial soil status for different parameters was determined from the soil samples collected from the study site before the start of the experiment. The sampling was done from ten sites and the analytical results were averaged. To study the nutrient build-up, five soil samples were taken from each land use and analysed for various constituents. The samples were taken in the first week of May every year after the winter crops were harvested and before sowing the summer crops. The soil samples from the horticulture and agro-forestry treatments were also taken during this time of the year. The chemical analysis of soil and runoff samples was done as per Jackson (1973).

Table 1. Vegetation cover, livestock and soil and water conservation measures in different land use systems

Land use	Slope (%)	Crops / Trees	Livestock	Soil conservation measure
Fodders	32.0	*Zea mays*, *Stylosanthes guyanensis, Avena sativa, pisum sativum*, *Setaria sphaselata, Panicum maximum, Thysanolaena sphacelata*	Cows, pigs, rabbits	Contour bunds,trenches, grass water-ways
Forest	38.0	*Alder nepalensis, Albziia lebbeck, Acacia auriculiformis*	None	None
Agro-forestry	32.2	*Ficus hookerii, Eucalyptus amygdalina, Pinus longaeva, Ananas comosus*, *Phaseolus spp., Psidium guajava*	Goats, rabbits	Contour bunds
Agriculture	32.4	*Phaseolus spp., Raphanus sativus, zea mays*, *Oryza sativa, Zingiber officinale, Curcuma longa, Arachis hypogaea, Avena sativa*, *Panicum spp.* on risers	Cows	Contour bunds, bench terraces grass water- ways
Agri-horti-silvi-pastoral	41.8	*Phaseolus spp.*, *Carica papaya*, *Citrus spp., Zingiber officinale, Solanum spp., Alder nepalensis, Ficus hookerii,Psidium guajava*	Pigs, goats	Contour bunds half-moon terraces, grass water-ways
Horticulture	53.2	*Prunus persica, Pyrus communis, Citrus spp., Citrus lemon, Psidium guajava* vegetables	None	Same as above
Shifting cultivation	45.0	Mixed cropping	None	None

Results

Soil properties

During the ten year study, there was a substantial build-up of available P over the initial status in all the new land use systems as compared to the shifting cultivation, in which the available P status remained constant (Figure 1). The maximum increase was found in the horticulture land use, where it increased from 2.7 to 24.9 mg P/kg soil, followed closely by agri-horti-silvi-pastoral (2.7 to 21.4 mg P/kg soil), agriculture (2.7 to 17.6 mg P/kg soil) and livestock based (2.7 to 16.2 mg P/kg soil). The increase in available soil P may be attributed partly to the increase in soil pH under new land use systems from 4.9 to 5.4 and partly due to application of phosphoric fertilizers in these land uses (Sharma and Tripathy 1999). The experimental soil had exchangeable Al concentrations of almost toxic amounts, but continuous cropping in the new land use systems ameliorated the soils to large extent. Maximum decrease in exchangeable Al content was from 117 mg Al/kg soil to 30 mg Al/kg soil in the livestock based land use system followed by forestry land use where it decreased up to 40 mg Al/kg soil (Figure 1). The grasses and forest trees had more ameliorating effect and reduced the toxicity of Al. Like P, the build up of available K was significant in the new land use systems.

Interestingly, the available K was highest in the shifting cultivation during the first (160 mg K/kg soil) and second year (146 mg K/kg soil) of study. This could easily be attributed to the burning of forest vegetation in the shifting cultivation at the beginning of the study. The available K was subsequently reduced in shifting cultivation and was a little below the initial soil status (105 mg K/kg soil), however it continued to increase in other land use systems, highest being 185 mg K/kg soil in the horticulture land use. The Ca content of soil was also found to increase in the new land uses, more prominently in forestry and agro-forestry land uses. It shows that tree plantation and fall of litter (leaves with petioles) had affected the increase in Ca content of the soil. Similar trend was observed in pH increase where it increased from 4.9 to 6.3 in forestry and 6.2 in agro-forestry land uses.

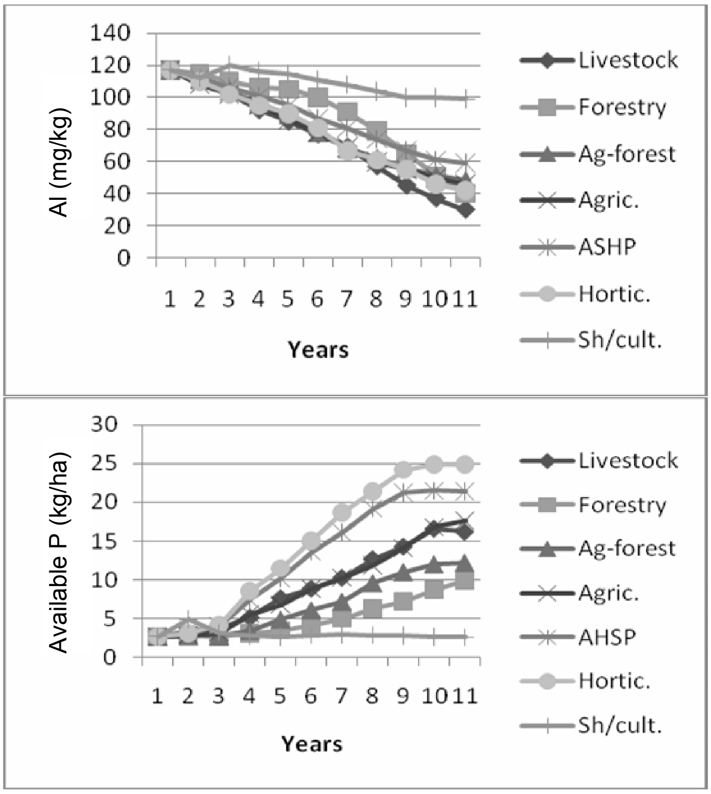

Figure 1. Change in Al and available P content of soil under various land use systems over the years.

Table 2. Effect of land use, rainfall and their interactions on groundwater recharge and sediment yield.

Land use	Rainfall (mm)						
	2195	2705	2770	2599	2288	1992	Mean
	Groundwater Recharge (mm) and Sediment Yield (t/ha) (in parentheses)						
Livestock based	738 (0.14)	1212 (0.16)	1294 (0.28)	1101 (0.18)	835 (0.10)	555 (0.09)	956 (0.16)
Forestry	426 (0.60)	729 (1.15)	746 (1.41)	663 (1.31)	477 (0.70)	338 (0.65)	563 (97.2)
Agro-forestry	560 (0.35)	954 (0.70)	984 (0.75)	870 (0.74)	633 (0.37)	459 (0.27)	742 (0.53)
Agriculture	731 (0.04)	1219 (0.09)	1289 (0.24)	1102 (0.22)	831 (0.04)	570 (0.03)	957 (0.11)
Agri-horti-silvi-pastoral	679 (0.20)	1134 (0.37)	1198 (0.36)	1021 (0.36)	769 (0.18)	526 (0.11)	888 (0.26)
Horticulture	516 (0.65)	897 (1.01)	914 (1.24)	815 (0.80)	590 (0.70)	420 (0.51)	692 (0.82)
Shifting cultivation	152 (29.50)	260 (45.80)	274 (44.99)	231 (36.10)	168 (34.19)	125 (26.69)	202 (36.21)
Mean	543 (4.47)	915 (7.04)	957 (7.04)	829 (5.67)	615 (5.18)	426 (4.05)	

Soil erosion and water yield

The results showed that on average, 0.09 to 1.41 tonnes of sediment yield ha^{-2} and more than 90% of rainwater was retained *in-situ* in new land use systems as against 36.21 tonnes of sediment and 66.3% rainwater retention in shifting cultivation (Table 2). Due to more infiltration of rainwater in the soil because of good vegetation cover, the runoff has considerably reduced, resulting in low flows to river channel and reduced sediment load in the runoff. Maximum *in-situ* infiltration was 39.3% of rainfall in livestock land use and minimum (8.2%) in shifting cultivation. This shows reduction in surface and base flows in new land uses due to sufficient vegetation cover. The enhancement of soil moisture was beneficial for the winter crops when there are no or little rains. The interactional effect of amount of rainfall and land uses was highly significant, while maximum soil loss was 44.99 t/ha in the shifting cultivation during the year when rainfall was 2770 mm and minimum, 0.09 t/ha in livestock based land use when annual rainfall was 1992 mm.

Crop productivity

The crop yield increase in new land uses was, on average, 2.6, 2.3, 2.1, 2.7, 3.2, 3.1, 1.9, 2.3, 2.5 and 3.7 times higher in case of rice, maize, ginger, turmeric, radish, sweet potato, pine-apple, citrus, guava and grasses/fodders, respectively, over the yields from the shifting cultivation.

Conclusion

Shifting cultivation is an age-old practice of land use. It was alright when the population was small, the food requirements were limited, and the shifting cycle was 25 to 30 years. Within this long period, the forest vegetation used to be sufficient to burn and add enough nutrient to sustain soil fertility to get optimum productivity. However, with increases in demographic pressure, the shifting cycle has come down to 2 to 10 years. The land does not have enough time for the rejuvenation of vegetation. The soil fertility is on the decline, the productivity is low and the system has become uneconomical. Furthering the woes, the high rainfall received in the region and mismanagement of rainwater has resulted in extreme soil erosion through runoff in the hills and silting of river beds and floods in the valley areas. The new land use systems tried are soil health friendly, highly productive, eco-friendly and sustainable and need to be popularized to replace shifting cultivation, reduce soil erosion, judicious management of rainwater as well as improve soil health, productivity and quality of life of the people.

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Impact of Tillage and Maize Cropping System on the Physical Properties of a Kaolinitic Soil in the Brazilian Coastal Tablelands

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Abstract

The objectives of this work were to evaluate (i) the effects of tillage and maize crop systems on the physical properties of a kaolinitic soil (Udic Kandiustalf) in the Brazilian coastal tablelands, and (ii) the relationship between maize productivity and soil physical quality (SPQ). The experiment was a 3 x 2 factorial replicated four times in a randomized complete block (RCB) design arranged in a split-plot layout. Three tillage methods (no-till, NT; chisel plow, CP; and conventional till, CT) and two maize cultivation systems (sole maize, SM; and maize-pigeon pea intercropping, MP) were tested. Plots fallowed for seven years, arranged in the RCB design, were also analyzed. Soil samples were collected seven years after the beginning of the experiment (0-20 cm) and analysed for water-stable aggregates (WSA), aggregate mean weight diameter (MWD), available water (AW), bulk density (ρ_b), macroporosity (MP), microporosity (mP), and saturated hydraulic conductivity (k_{sat}). Cultivation systems had no significant effects on soil properties. Fallow significantly improved all the variables studied. CP and NT had higher MP, WSA and MWD, and lower mP and ρ_b than CT. Except for a decrease in MWD, chisel subsoiling in CP did not affect soil properties, compared with NT. A significant positive correlation was observed between maize productivity and SPQ.

Key Words

kaolinitic soils, soil quality, *Cajanus cajan, Zea mays*

Introduction

Kaolinitic soils are the most widely occurring soils in the tropics. The use of kaolinitic soils for continuous cropping must overcome many physical and chemical limitations, especially those related with the compaction due to frequent tractor traffic and lack of organic inputs (Juo and Franzluebbers 2003). Therefore, soil management strategies that combine reduced or no-till and high plant residue inputs are pivotal to the long-term sustainability of these soils (Juo and Franzluebbers 2003; Juo 1980; Nyamadzawo *et al.* 2008; Nyamadzawo *et al.* 2009). Crop successions between cash crops and cover crops have been pointed as an efficient alternative to increase residue inputs in many regions (Valpassos *et al.* 2001; Machado *et al.* 2005; Bayer *et al.* 2006; Villamil *et al.* 2006; Zanatta *et al.* 2007). However, in many subhumid and semiarid regions of the tropics, the rainy season is relatively short to allow two cropping cycles in the same year. Pigeon pea presents a high temporal complementarity of resources with maize due to its slow initial growth rate (Gilbert 2004). Because of this complementarity and of its drought tolerance, pigeon pea is amenable to being intercropped with maize, and can stand the dry period after the harvest of the cash crop, therefore, contributing with the production of plant residues during the dry period in subhumid and semiarid regions.

The objectives of this work were to evaluate (i) the effects of tillage and maize crop systems on the physical properties of a kaolinitic soil (Udic Kandiustalf) in the Brazilian coastal tablelands, and (ii) the relationship between maize productivity and soil physical quality (SPQ).

Methods

Experimental Setting

This work was carried out in a kaolinitic Udic Kandiustalf at the Umbauba Experimental Station (Umbaúba, Sergipe State, Brazil). The experiment was a 3 x 2 factorial replicated four times in a randomized complete block (RCB) design arranged in a split-plot layout. Three tillage methods (no-till, NT; chisel plow, CP; and conventional till, CT) and two maize cultivation systems (sole maize, SM; and maize-pigeon pea intercropping, MP) were tested. Tillage treatments were imposed from 2002 to 2008, whereas cultivation system treatments were applied from 2006 and 2008. Before 2006 all the plots had been sown with maize and pigeon pea, in an intercropping system. Plots fallowed for seven years, arranged in the RCB design, were included as soil quality references.

Soil and crop management
Seven days before sowing, glyphosate was sprayed in NT and CP plots. CT plots were plowed with a disk plow and disked twice, immediately before sowing. CP plots were chisel subsoiled at ~30 cm depth. Nitrogen, phosphorus and potassium were provided as ammonium sulfate (90 kg N/ha), simple superphosphate (60 kg P_2O_5/ha) and potassium chloride (60 K_2O/ha), respectively, in both cropping systems (SM and MP). Maize (double hybrid AGN 3100) stand was 50000 plants/ha (80 x 50 cm, two seeds every 50 cm) in both cropping systems. Pigeon pea was sown at the same time as maize. Four pigeon pea seeds were placed 25 cm apart from maize plants, in the same row as the crop. Maize was harvested 120 days after sowing. Pigeon pea plants were left standing in the field during the dry period and killed with glyphosate (NT and CP) or plowed (CT) immediately before the maize sowing in the next year.

Soil sampling and analyses
Soil samples were collected (0-20 cm depth) in September 2008, after maize harvest, and analyzed for the following physical variables: available water between -10 e -1500 kPa (AW) (pressure plate method); soil bulk density (ρ_b) (7.5 to 12.5 cm depth); water-stable aggregates (WSA) and aggregate mean weight diameter (MWD) (Kemper and Rosenau 1986), macro- and microporosity (MP and mP) (Embrapa 1997). Saturated hydraulic conductivity (k_{sat}) was obtained in the field, at the time of soil sampling, using the double concentric ring method (Reynolds *et al.* 2002). The same sampling procedures and analyses were used for cropped and fallow plots.

Statistics
Split-plot ANOVA was used to evaluate the effects of tillage, cropping systems and the interaction between these factors on the soil variables. Whenever cropping system effects and interactions were not significant ($p > 0.10$), the following contrasts were used to compare the effects of (i) the conversion of cropping plots in fallow (NT + CP + CT vs. Fallow), (ii) the soil layer inversion in cropped areas (NT + CP vs. CT) and (iii) the chisel subsoiling in plots where no-inversion methods were applied (NT vs. CP).

Principal components analysis (PCA) was used to evaluate the treatment effects on the soil physical quality (SPQ), expressed as the combined response of the seven soil properties. Prior to PCA, data were standardized by each soil property totals. Principal components were characterized by Pearson correlation coefficients between the sample scores in PCA components and their respective values for each variable. Treatment effects on SPQ were tested using MANOVA. The same contrasts described above for the univariate analyses were used for the SPQ analysis. In this case, treatment effects were compared by *multi-response permutation procedures* (MRPP, Mielke Jr. and Berry 2007). The correlation between maize productivity and SPQ was evaluated by the Pearson correlation coefficient between productivity data and the samples scores in both components of the PCA plot.

Results
Cropping system effects and the interactions between this factor and tillage methods were not significant ($p < 0.10$) for any of the soil properties evaluated. This may be explained by the short period of application of cropping system treatments in our study (2 years). Conversion of cropped areas in fallow had a significant impact in all the soil properties (Table 1). This conversion led to increases in AW, MP, MWD, WSA and k_{sat}, and decreases mP and ρ_b. Improvements in soil physical quality under fallow have been attributed to greater residue input, higher protection of soil surface against the impact of rainfall, higher macrofaunal activity and presence of plant species with deep root systems. Soil layer inversion in CT plots lead to significant decreases in MP, MWD and WSA and increments in mP and ρb (Table 1). Except for a decrease in MWD, chisel subsoiling in CP did not affect soil properties, compared with NT. (Table 1).

Regarding the SPQ, about 89% of the original variability in soil physical properties was represented in a 2-D PCA plot (Figure 1). Differences in SPQ were mainly observed along PC1, which was associated with 56% of the variability of the original variables. PC2 explained 28% of the data variability. PC1 was highly correlated ($p < 0.001$) with all the variables, except mP. Along PC1, from the left to the right, increases were observed in MP, MWD, WSA, k_{sat} and AW; whereas ρb increased in the opposite direction (Table 2). An increasing gradient of mP and AW was observed toward the top of PC2, whereas MP varied in the opposite direction.
MANOVA indicated that SPQ was affected by tillage method ($p = 0.04$), but not by cropping system ($p = 0.55$) or the interaction of these two factors ($p = 0.24$). Contrast analyses showed that SPQ differed between

fallow and cropped areas ($p < 0.001$), and between areas with (CT) and without (CP+NT) soil layer inversion ($p < 0.001$). Chisel subsoiling did not significantly affected SPQ ($p > 0.10$). In summary, an increasing gradient of SPQ was observed along PC1, as follow: CT → CP+NT → Fallow (Figure 1). Maize productivity was significantly correlated with shifts in SPQ along PC1, but not with PC2.

Table 1. Contrasts comparing the effects of soil tillage on the physical properties

			AW	MP	mP	ρ_b	MWD	WSA	k_{sat}
Effect	Contrasts	Treatments	cm^3/cm^3	cm^3/cm^3	cm^3/cm^3	g/cm^3	mm	g/hg	Cm/min
Conversion of cropped areas in fallow	Fallow vs. NT+CP+CT	Fallow	0.101	0.171	0.203	1.52	1.30	83	0.57
		NT+CP+CT	0.080	0.152	0.221	1.59	1.12	74	0.34
		p	<0.01	<0.10	<0.05	<0.05	<0.10	<0.01	<0.05
Soil layer inversion methods	CT vs. NT+CP	CT	0.082	0.138	0.211	1.63	0.96	71	0.26
		NT+CP	0.079	0.159	0.198	1.58	1.20	75	0.37
		p	ns	<0.05	<0.05	<0.10	<0.05	<0.10	ns
Chisel subsoiling	NT vs. CP	NT	0.082	0.160	0.199	1.58	1.31	77	0.45
		CP	0.076	0.160	0.198	1.58	1.10	74	0.29
		p	ns	ns	ns	ns	<0.05	ns	ns

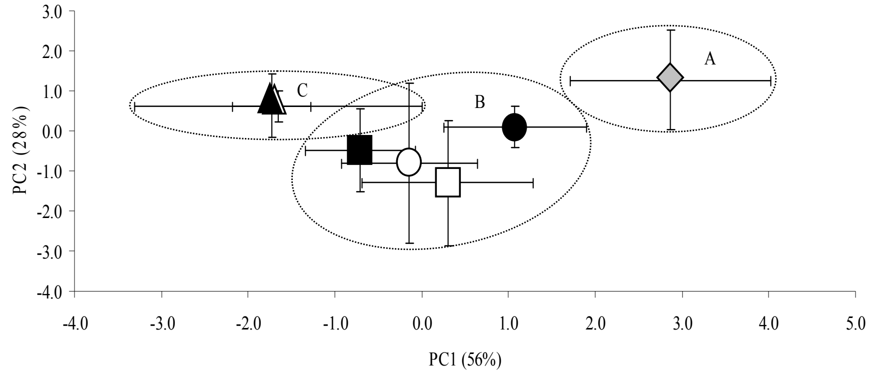

Figure 1. Changes in SPQ as a function of tillage methods and maize cropping systems. CT, CP and NT are represented by triangle, squares and circles, respectively. MP and SM systems are represented by full and open symbols. The diamond indicates fallow. Horizontal and vertical bars indicate ±1 SD. SPQ averages within the same ellipses did not differ ($p<0.05$) according with MRPP. PC: Principal components.

Table 2. Pearson correlation coefficients between soil properties and SPQ expressed as the sample scores in the principal components (PC1 and PC2) of PCA

	Soil physical variables						
	AW	MP	mP	ρ_b	MWD	WSA	k_{sat}
PC1	0.605***	0.732***	0.085^{ns}	-0.860***	0.733***	0.744***	0.598***
PC2	0.743***	-0.568**	0.972***	0.037^{ns}	0.010^{ns}	-0.005^{ns}	0.074^{ns}

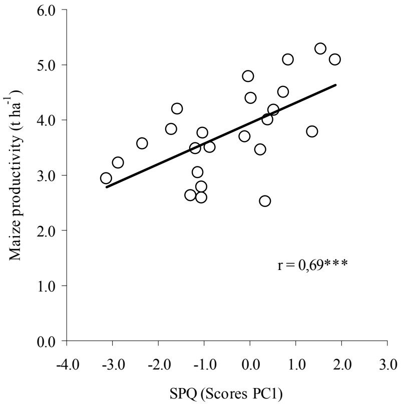

Figure 2. Correlation between maize productivity and SPQ expressed as the sample scores in the first principal component (PC1) of PCA. *** Significant at $p < 0.1\%$.

Conclusions

The maize + pigeon pea intercropping system proposed in this study does not affect soil physical quality and maize productivity in the short term (2 years). Fallow and tillage methods with no soil layer inversion promote improvements in the SPQ in the medium term (7 years). Chisel subsoiling in CP (~ 30 cm depth) does not affect soil properties, compared with NT. In the soil studied, maize productivity is correlated with SPQ.

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Increase in ground cover under a paddock scale rotational grazing experiment in South-east Queensland

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Abstract

Time-controlled rotational grazing (TC grazing) has been adopted in some Australian rangelands over the last two decades to provide graziers with a relatively higher herbage production over traditional practices. This grazing system, which involves short periods of intensive grazing, has raised concerns about the sustainability and environmental impacts on ecosystem health. Ground cover as an indicator of soil health and sustainability was measured over a 6 year period using paired research paddocks treated by TC and continuous grazing practices in southeast Queensland. The TC grazing achieved and maintained a 72% average ground cover during the study period as compared with 59% for continuous grazing. In the second period of the study (2004-2006), increase in ground cover under TC grazing was as high as 85% as compared to 65% for continuous grazing. Use of TC grazing resulted in up to 92% cover when the soil was in good condition, whereas under continuous grazing ground cover did not increase beyond 70%. The improvement of ground cover under TC grazing in the study area was attributed to the effects of long rest periods, providing an exceptional chance of recovery and regrowth over wet seasons dominated by a high frequency of rainfall events.

Key Words

Surface cover, time-controlled grazing, continuous grazing, rangeland, soil protection.

Introduction

It is well known that grazing systems greatly affect vegetation cover that is the primary layer for soil protection against water erosion. Ground cover intercepts and absorbs the energy of rainfall and impedes the flow of runoff. It resists the erosive force of flowing water and maintains a high infiltration rate over a longer period of time during runoff events. Decrease in vegetation cover increases the exposure of soil surface to raindrop and runoff impacts (Busby and Gifford 1981) ultimately increasing runoff and soil loss. In addition to the effects of surface cover on soil erosion, it also provides a favourable habitat for soil organisms and improves physical and chemical characteristics of soil surface.

Time-controlled rotational grazing (Savory and Parsons 1980; McCosker 2000) as an alternative to continuous grazing has potential to increase above and below ground organic materials. Under rotational grazing, some studies report on the positive effect of rest periods and grazing exclusion on the increase of organic materials and the subsequent decrease in runoff and soil loss (McGinty *et al.* 1979; Wood and Blackburn 1981) when compared with continuous grazing and even non-grazed areas.

In southeast Queensland, time-controlled (TC) grazing is the main alternative to continuous grazing. This paper briefly provides information on the effects of TC grazing on ground cover in the region to address some environmental concerns of such a practice on surface soil protection. The results are based on a 6 year period of data collected from 2 research paddocks comparing TC and continuous grazing systems.

Methods and materials

Study area

The research was conducted at “Currajong”, a grazing property 40 km west of Stanthorpe in the semi-arid region of south-east Queensland, Australia. The study area, known locally as Traprock, is located in the catchment of the MacIntyre Brook at the northern headwaters of the Murray Darling basin. The annual rainfall for this area is 645 mm, with a summer dominance of around 70%, which is characterized by relatively high frequency of medium to large events of short (thunderstorms), and long (cyclonic depressions) durations. The soil is shallow to moderately deep with a hard setting brown to dark clay loam underlined by a bleached A2 horizon. Vegetation is Eucalypt open woodland with understorey native and naturalized perennial grass species dominated by a desirable species known as Queensland blue grass [*Dichanthium sericem* (R. Br.) A. Camus].

Definition
Ground cover is one of the main attributes of vegetation in grazing practices often recognized as a reliable indicator of soil protection and sustainability. It refers to any non-soil material remaining on or near the ground that protect the soil surface against erosive forces of raindrops and overland flow (McIvor *et al.* 1995). The definition of ground cover is originally based on the commonly used method of aerial plant cover (Greig-Smith 1983) which measures the proportion of the ground occupied by perpendicular projection of the aerial parts of plants but includes all live/dead organic materials plus stone cover.

Treatments
The research was conducted using two paddocks, one under time-controlled and the other under continuous grazing practices. These paddocks were each divided into two sections (sub-treatments) based on the physiographic features of the land (slope and soil depth). Under this arrangement, the sub-treatments 1 and 2 belong to TC grazing, and the sub-treatments 3 and 4 belong to continuous grazing. Similarities between sub-treatments 1 and 4 (deep soils and gentle slopes) on the one hand and between sub-treatments 2 and 3 (shallow soils and steep slopes) on the other hand, reduces error when comparing the two grazing treatments.

Stocking
The paddock of continuous grazing was grazed with a constant stocking rate of 1.6 DSE (Dry Sheep Equivalent)/ha. This grazing intensity is normal in the region and exerts a light to moderate pressure on the pasture. The other paddock was stocked under TC grazing system with high stocking rates of differing grazing/rest periods depending on feed availability and the rate of grass growth in the paddock. Much care was taken to keep the total DSEdays/ha similar between the two grazing systems. More details on the stock management and sampling have been reported by Sanjari *et al* (2008).

Results

The results on the ground cover show a general trend of decrease over the first period of the study (2001-2003) from around 65 to 50% in both treatments, but more pronounced under continuous rather than TC grazing treatments (Figure1A). Such decreasing trend in the cover can be explained by a similar decrease in the annual rainfall over the same timeframe. This period coincides with a moderate water shortage over the years of 2002 and 2003 with a total rain of 8 – 17 % below the long term average in the region.

Unlike the first period of the study, ground cover in 2004 increased to 75% reaching to 90% by end of the second period (2004-2006) under TC grazing, while it remained from 62 to 68% in continuous grazing. The overall increase in the cover, from 2004 to 2006 appears to be associated with the high rainfall in 2004, which was around 23% above the long term average rainfall for the region. Although the total rainfall decreased in 2005 and 2006 to slightly below the long term average rainfall, the ground cover continued to increase under TC grazing but not under continuous grazing.

The different responses by the sub-treatments shown in Figure1B reflect the combined effects of the grazing treatment and the soil variation (depth and slope). It shows that sub-treatment 1 of TC grazing with a better soil condition achieved the highest cover level over the study period and the sub-treatment 3, under continuous grazing management with a poor soil condition, the lowest. This is despite the fact that in 2001 all the four sub-treatments had about the same level of ground cover (65%). Surprisingly, ground cover in sub-treatment 2 of TC grazing increased to a higher level than that of sub-treatment 4 in continuous grazing from 2004 to 2006 despite having a poorer soil condition, thus highlighting the importance of management effect.

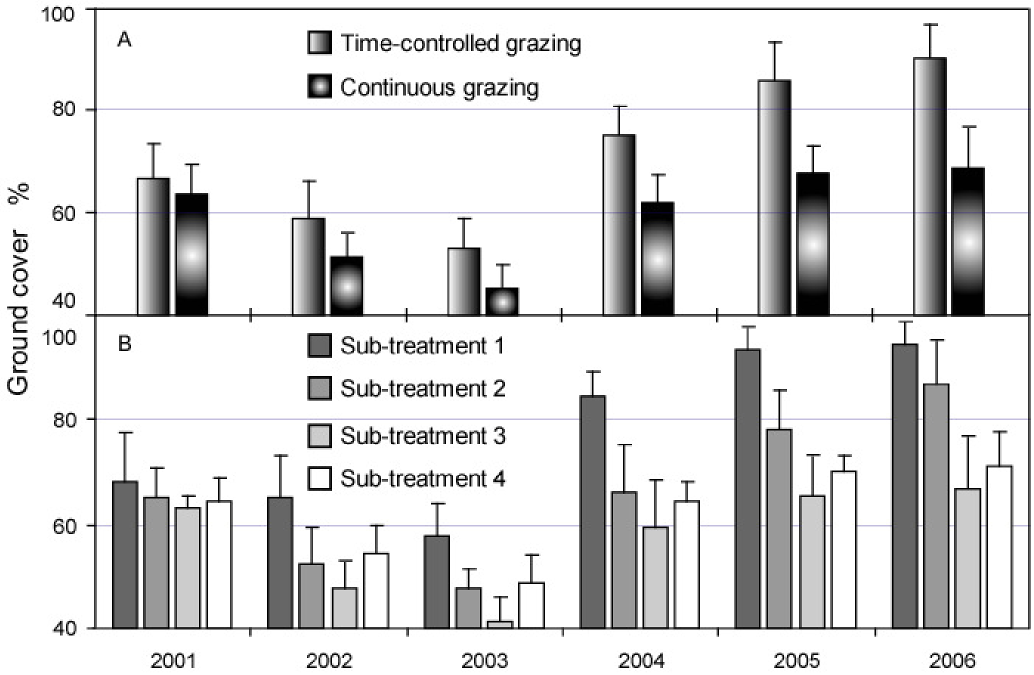

Figure1. Ground cover changes under time-controlled and continuous grazing in the study area.

Analysis of variance (two tailed T test) on the pooled data verified the significantly higher ground cover achieved under TC grazing than continuous grazing. The average increase in surface cover under TC grazing (time-controlled *minus* continuous) was 7% ($p \leq 0.05$) over the first period and then increased to the higher level of 16% ($p \leq 0.01$) during the second period (2004–2006).

The results of the ANOVA on the data of sub-treatments presented in the table 1 show the superiority of TC grazing even at sub-treatment level over continuous grazing. For instance the mean cover for sub-treatment 1 (TC grazing) had been 8% and 22% more than the one for sub-treatment 4 (continuous grazing) over the first (2001-2003) and the second (2004-2006) periods, respectively.

Table 1. Ground cover ANOVA between sub-treatments over the first and the second periods

Sub-treatments	+Sub-treatment 1		+Sub-treatment 2		+Sub-treatment 3	
	1st	2nd	1st	2nd	1st	2nd
-Sub-treatment 2	+9%***	+16%***				
-Sub-treatment 3	+14%***	+27%***	+5%*ns*	+11%***		
-Sub-treatment 4	+8%***	+22%***	-1%*ns*	+6%***	-6%*	-5%**

*- $p < 0.1$; **- $p \leq 0.05$; ***- $p < 0.01$; *ns* – non significant

Increase in ground cover reported here, is inline with residue accumulation reported earlier by the authors (Sanjari *et al.* 2008) under TC grazing. Ground litter is derived from primary plant production and was a major contribution to ground cover, thus any changes to the cover levels can be directly related to pasture production and management. In this study, a major coincidence of an exceptionally long rest period of 156 days with multiple favorable conditions of rain and temperature produced a massive pasture production in 2004 that resulted in large amounts of residue and in turn a high percentage of ground cover.

Results of a catchment scale runoff experiment in the study area (Sanjari *et al.* 2009) support the findings of this paper on ground cover improvement under TC grazing. The authors found a strong link between the ground cover levels and runoff and soil loss, introducing a minimum safe surface cover threshold of 70% for the study area to be maintained by the graziers.

The improvement of ground cover in TC grazing is attributed to the proper management of grazing frequency and the durations as well as the provision of adequate rest periods. Application of long rest periods following short durations of intensive grazing provides a highly favourable condition for the defoliated plants in the pasture to recover over the growth season where a high frequency of rainfall events are expected in the study area.

Conclusion

Time-controlled grazing, which involves long rest periods under a flexible grazing management, provides a significantly higher ground cover level than continuous grazing in the study area. Contrary to continuous grazing, TC grazing maintained a cover level above the minimum safe threshold recommended for the study area (70%) providing an effective soil surface protection against water erosion. Surface cover under the poor soil condition of shallow and steep slope is better maintained by TC grazing than continuous grazing.

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Increasing Water Efficiency in Greenhouse Cooling system in Arid Regions Using Sulfur Burning Technology

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Abstract

Formation of scaling deposits is a serious problem that affects cooling efficiency of the greenhouses in the arid regions, including the UAE. Scaling buildup in the evaporative cooling pads of the greenhouse blocks air flow entry and thus reduces cooling efficiency. Dissolved salts and high alkalinity of the source water are the major cause of scale formation. Most of the scaling inhibition studies and practices are focused on the industrial cooling water processes, however, no studies have been found on the removal of scaling deposits from greenhouse cooling systems. In this study, acidified water was introduced to remove and prevent future buildup of scaling deposits in greenhouse cooling pads. The acid water was maintained by utilizing sulfur by-product from gas production plant using sulfur burning equipment, the average pH of the acid water generated by this technique was 6.5. Eight greenhouses with severe to moderate scaling were selected for this study, where 6 of them treated with acidified makeup water and 2 with normal makeup water in the circulating cooling system of the greenhouse. Water samples were collected daily from each reservoir of the cooling systems, before emptying and after refilling with fresh makeup water, to measure the pH, EC, and the concentrations of cations and anions. The visual observations show that the acidified water was effective in removing the scaling deposits from the cooling pads; as a result the blockages of air flow entry were reduced in all greenhouses treated with the acidified water. The analysis of water samples also confirms that the acidified water was able to dissolve more salts from the cooling pads, as a result, the pH, EC, cations, and anions of the cooling water increased considerably after 24 hrs from adding new makeup water.

Introduction

Scale formation and salt deposits in greenhouse evaporative cooling pads have always been the major threats to the cooling efficiency of the greenhouses in the arid regions including the UAE. During the cooling process of the greenhouse, water evaporates off the pad leaving the dissolved salts and thus, increasing their concentration in the circulating water, this process ends up by precipitating and depositing the salts inside the cooling pad air flow access openings. These deposits reduce the wetting surfaces of the cooling pads, prevent uniform wetting, and reduce airflow through the cooling pads, and hence, reducing the efficiency of cooling process of the air while entering the pads and reducing the amount of cooled air that enters the greenhouses, and therefore, increase in maintenance and replacement costs of the pad.

The potential and speed of scaling and salt deposits increase when the makeup water, which is used for the cooling system in the greenhouses, contains significant amount of dissolved salts, having high pH, and high alkalinity accompanied by bicarbonates. Bicarbonate salts, which are dominant in water of the arid regions including the UAE, usually breakdown to carbonate salts during the cooling process and form scales. Calcium carbonate ($CaCO_3$) is the predominant component of scales deposited from natural water, especially in cooling water systems. The formation of $CaCO_3$ scaling on various surfaces has been extensively studied. Temperature and pH are known to be parameters of particular importance for $CaCO_3$ scale formation. The solubility of the salt decreases with temperature and pH, hence scaling frequently occurs when warm and high pH water is used.

No studies have been found on the scale inhibition and removal from greenhouse cooling pads, however, scaling is a well known problem in the industrial water cooling and heating processes (Shakkthivel *et al.* 2004) and received well attention and considerable investigations. Conventional methods for removing these deposits are expensive and laborious, however, one of the most promising ways to achieve this is to add scale inhibitors into the water (Darton 1997; Hasson *et al.* 1998; Bremere *et al.* 1999; Gill 1999). Many inhibitors have been used in industrial cooling water systems in order to solve these problems (Gehan *et al.* 1991). However, the popularity of inhibitors containing heavy metals is diminishing, because of the concern over their toxic effects (Lake 1988; Levi *et al.* 1988). As a result, the current trend for inhibitor usage is towards more environmentally friendly chemicals.

The objective of this study is to utilize the sulfur by-product from gas production plants in preventing or reducing scaling and salt deposits on the cooling pads by producing acidified water to control the pH of circulating water in the greenhouses. Low pH water tends to consume insoluble carbonates with hydrogen ions turning them into soluble bicarbonates and then into CO_2 and water. Thus, it will prevent the formation of $CaCO_3$ scaling.

Methods

The sulfur by-product from gas production plants, obtained from TAKREER Company, Al-Ruwais, Abu Dhabi, was used in this study to generate acidified water. The sulfur burning unit (Sweetwater Technology®) was installed at the College of Food Systems Farm, the UAE University, Al-Ain, UAE for the purpose of burning the sulfur and producing acid water. The average pH of generated acid water in this unit is 2.5 in the primary discharge line and 6.5 in the auxiliary discharge line. Water from both lines was collected in storage tank and adjusted to pH 6.2 - 6.5 before it is pumped to the distribution tank.

Eight greenhouses were selected to study the effect of acidified water in removing the scale and salt deposits from evaporative cooling pads. The initial conditions of the pads in greenhouses 1 to 6 were that they were older and severely blocked. The pads of greenhouse 7 and 8 were newer and contained less deposit. Acidified water was applied as makeup water to cooling system in greenhouses 1, 2, 3, 4, 7, and 8, while normal makeup water was supplied to greenhouses 5 and 6.

During system operation, water circulates from the reservoir to the top of the pad, then through the pad layers, and finally, collected at the bottom of the pad and send back to the reservoir. To dispose of accumulated salts and to control the system pH, the cooling system reservoir of each greenhouse was daily emptied and refilled with fresh makeup water. Before emptying each reservoir, water samples were daily collected from each reservoir as well as initial acidified and normal makeup water to measure the pH, EC, Ca^{++}, Mg^{++}, Na^+, Cl^-,$CO_3^=$, and HCO_3^-.

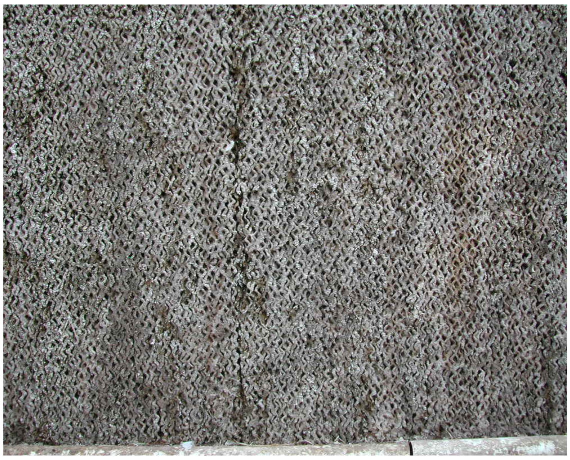
Results

The typical analyses of acidified and normal makeup water are presented in Table 1.

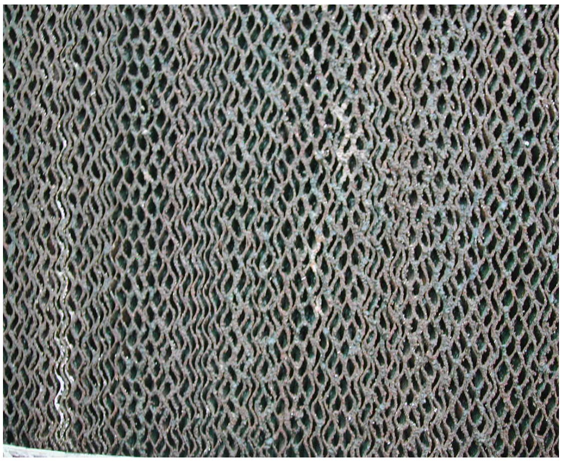
Table 1. The average values of pH, EC, Cations, and Anions in makeup water.

Makeup Water	pH	EC dS/m	Ca^{++} cmol/l	Mg^{++} cmol/l	Na^+ cmol/l	Cl^- cmol/l	$CO_3^=$ cmol/l	HCO_3^- cmol/l
Acidified	6.46	2.50	2.47	5.36	9.42	19.91	0.00	2.07
Normal	7.88	1.20	0.95	3.61	13.57	10.20	0.00	8.32

The preliminary results of daily changes of pH, EC, carbonate, and bicarbonate in the greenhouse cooling water indicated that the acidified water was effective in removing scale and salt accumulation from the cooling pads. The visual observations in Figures 1 and 2 showed clear evidence that acidified water effectively removed the deposits form the cooling pads.



Before treatment



After treatment

Figure 1. The effect of acidified water in removing scaling and salt deposits from cooling pads.

Initial After 24 hrs.

Figure 2. The effect of acidified water in removing scales and salt deposits from the cooling pad (dissolved salts in the reservoir of the cooling system).

The pH analysis in Figure 3 showed that there was an increase in the pH of cooling water in all greenhouses from 6.5 to about 9, however, increase in pH with the use of acid water was more significant than that of normal water, as the dissolved carbonates and bicarbonates increased the media pH over time by neutralizing the H^+ ions in the media solution.

The results also showed that the EC of the cooling water was increased from 2.5 to 9 dS/m with acidified water, and from 1.2 dS/m to 4 dS/m with normal water (Figure 4). This is attributed to the fact that acid water removes more accumulated salts of calcium and Magnesium, while the hardness, of normal water, precipitates calcium and other mineral salts, and thus, less changes in EC was observed with normal water.

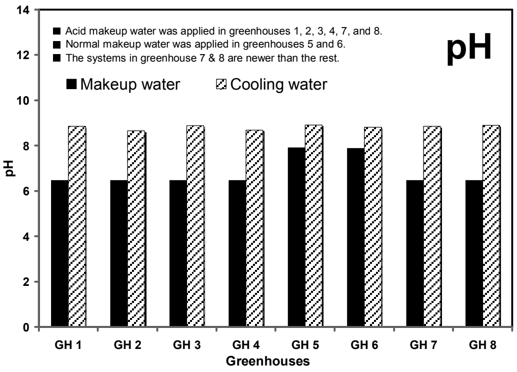


Figure 3. Average pH difference between makeup water and cooling water in the greenhouses after 24 hrs of application

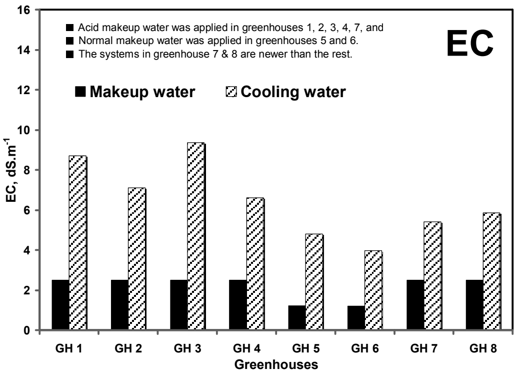


Figure 4. Average EC difference between makeup water and cooling water in the greenhouses after 24 hrs of application

Presence of carbonate was observed in all greenhouses (Figure 5), however, the concentration of carbonate in the cooling water was higher with acidified water. This was attributed to the acids dissolving more $CaCO_3$ and $MgCO_3$. As greenhouses 3 and 4 having more scales and salt deposits, application of acid water will take more time to dissolve the salts, hence, carbonate concentration of cooling water in the greenhouses 3 and 4 was much less.

The average number of changes of bicarbonate in the cooling water is presented in Figure 6. The results show that bicarbonate concentration was increased significantly after 24 hrs. of application in all greenhouses.

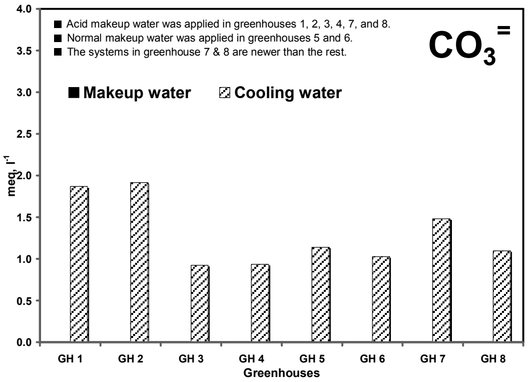


Figure 5. Average $CO_3^=$ difference between makeup water and cooling water in the greenhouses after 24 hrs of application

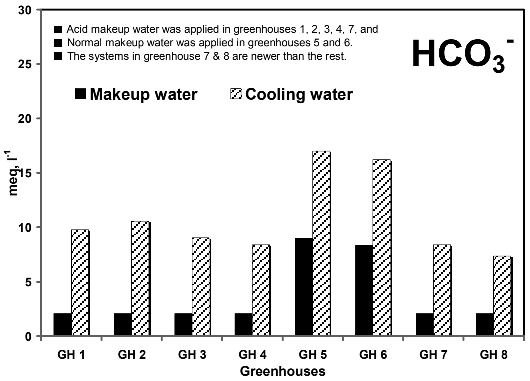


Figure 6. Average HCO_3^- difference between makeup water and cooling water in the greenhouses after 24 hrs of application

Conclusion

Application of acidified water in cooling systems of the greenhouses was significantly effective in removing scales and deposited salts from the evaporative cooling pads and prevents future deposits, and hence, improved cooling efficiency of the greenhouses, extending the life of the cooling pads, and reduced the maintenance and replacement costs.

Acknowledgement

This research was part of the Sulfur Project, which externally funded by the Japan Cooperation Center, Petroleum (JCCP) in cooperation with Nippon Oil Research Institute (NORI), Japan. We thank the Research Affair, UAE University, JCCP and NORI for the follow-up and facilitating administration work. Our deepest thanks are to Prof. Satoshi Matsumoto, Faculty of Bioresources Science, Akita Prefectural University, Japan, for his scientific guidance.

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Influence of amendments and soil roughness on nutrient transport from soil under different rainfall intensities

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Abstract

Continuous application of P fertilizers to saturated soils occurs to such an extent that P loss in surface runoff has become a priority management concern. To reduce P transport to surface water bodies, many strategies and management practices have been investigated. There is a need to work out strategies for the soil that are already rich in P. In many areas, soils are so P-enriched that without further P addition, 16 to 18 years of cropping would be needed to deplete it. Residues from water treatment facilities (WTR) have been extensively tested for this purpose under crop or grass cover, but less is known about what happens when it is applied to bare soil. Similarly, blast furnace slag (BFS) has been studied for its use as a filtering material in wastewater treatment plants, but its use on agricultural land for P control has not been reported. In this study, bare soil was amended with these two industrial wastes to observe the P concentration in runoff water. Soil was amended with P at 400 kg/ha, while BFS and WTR were applied at 50 g/kg soil. Bare soil surface, with two roughnesses (low and high), was exposed to two simulated rainfall intensities (30 and 65 mm/h). Each rainfall treatment was conducted three times on each amended soil surface with a constant rainfall amount of 60 mm. Regardless of rainfall intensity and soil roughness, there was an increasing trend of P concentration in runoff water from unamended control plots over the time of runoff, while the trend of P concentration tended to decrease from the BFS and WS amended soils. Though the trend was declining, the P concentrations were higher from BFS amended plots as compared to control and WTR amended plots. The P concentration was lower in both amended plots during the third run under both rain intensities. However, P concentrations were lower with high rainfall intensity, mainly due to the dilution factor. This study affirms the ability of WTR to reduce P mobility from bare soils however further studies are needed to test the effectiveness of BFS under field conditions.

Key Words

Phosphorus runoff, soil roughness, rainfall intensities, nutrient transport

Introduction

Chemical fertilizer application to land has increased, especially in developing countries, and world P fertilizer demand was predicted to increase by approximately 2.7% per year from 2004 to 2008. Continuous application of P fertilizers saturated the soils to such an extent that without further P addition, 16 to 18 years of cropping corn or soybean would be needed to deplete the soil test P content (Mehlich III) of soil from 100 mg P/kg to the threshold agronomic level of 20 mg P/kg. To reduce P transport to surface water bodies many strategies and management practices have been investigated that include the use of different amendments. Our knowledge on the effectiveness of different amendments on bare soil is scarce. Therefore, in the current study, some amendments have been used to reduce the P lost from the soil. Blast furnace slag (BFS) is one of the materials which has been used for P removal from waste waters. But BFS has not yet been used to reduce P mobility from agricultural lands. Similarly, drinking water treatment residuals (WTR) are also effective due to their high P-sorbing capacity. Several field and lab studies have been conducted to evaluate the use of WTR as a P sorbent and have reported that WTR significantly reduces P losses. However, the performance of these amendments under changing soil surface roughness has not been fully explored. The objectives of this study were to evaluate i) the effect of different rainfall intensities on P concentration in runoff from amended soil ii) potential use of BFS in reducing P concentration in runoff and iii) effect of soil roughness and rainfall intensity on the performance of WTR and BFS.

Methods

Tohaku loam soil (Fulvudand) was air dried, passed through a 2 mm sized sieve and packed in a steel pan (100cm x 50cm x 15.2cm). Each pan was part filled with a gravel filter to facilitate lateral flow. Top 5 cm of soil was amended with blast furnace slag (BFS) and residues from water purification facility (WTR) at the rate of 50 g/kg soil. Phosphorus (P) fertilizer in the form of KH_2PO_4 was applied at the rate of 400 kg P/ha and was mixed in the top 5cm soil. Slop was adjusted at 8%. Two rainfall intensities 30 and 65 mm/h were used with the rainfall application of 60 mm. Each treatment was subjected to three consecutive runs. The soil surface of each treatment was made with low or high roughness. To achieve the low soil roughness a spade with a blade 2cm in length was used, while for high soil roughness a spade with a blade of 5 cm length was used. Three soil amendments, two soil roughness, two rainfall intensities and two replications with three runs gave a total of 72 runs. Water samples from runoff water were collected at different time intervals after the runoff started. Immediately after the collection, water samples were filtered through a 0.45 µm filter. Concentration of DRP, K, Fe and Al in runoff water was recorded with an Inductively Coupled Plasma Spectrometer (ICP).

Results

Effect of low rainfall intensity (30 mm/h)

Dissolved reactive phosphorus (DRP) concentration in runoff varied greatly under all treatments. Irrespective of soil roughness, the concentration of DRP in unamended (control) plots was lower at the start of first run (Figure 1) and DRP concentration increased with the increase in time of water runoff over the surface. Contrary to the unamended plots, DRP concentration started to decrease with the time of runoff over the plots amended with sludge from water purification plant (WTS) and blast furnace slag (BFS). In WTS amended plots, DRP concentration was higher at the start of first run under low soil roughness condition and a declining trend was observed (Figure 1). A similar trend was observed for the second run while in the third run DRP concentration was relatively stable. In BFS amended plots with low soil roughness (LSR), DRP concentration was higher at the start of first run and the concentration started to decrease with runoff time. In the second runs, DRP concentration remained almost steady while in the third run DRP concentrations were lower than first and second runs. The change in soil roughness from low to high did not change the overall trend of DRP concentration in runoff water under 30 mm/h rainfall intensity (Figure 2). For high soil roughness (HSR), DRP concentration from the control plot increased in first dry run with the passage of runoff time and remained steady during second and third runs. For the WTR treatment DRP concentration was higher at the start of each run but with runoff time DRP concentration decreased. Similarly, for BFS amended soil, the concentration of DRP also decreased with the passage of runoff time in all three runs.

Effect of high rainfall intensity (65 mm/h)

The trend over time of DRP loss did not change significantly with the increase in rainfall intensity. Under low soil roughness, DRP concentrations in the control treatment increased with the time of runoff in all three runs (Figure 3). For the WTS amended plot, DRP concentrations also decreased in the first run. In the second run, DRP concentrations were higher at the start, but later the trend was linear, while in the third run the DRP concentration in runoff water was relatively steady. In BFS amended plots, the DRP concen-tration decreased with time of runoff for all three runs and minimum DRP concentrations were recorded for the third run. Under high soil roughness, the DRP concentration remained stable with runoff time for the control plot (Figure 4). Plots amended with WTR showed a decrease in DRP concentration during the first run, while in second and third run the DRP concentration remained relatively stable. For BFS amended plots, a decrease in DRP concentration was sharp in first run, but in the second run the DRP concentration remained steady. In the third run, the DRP concentration was steady, but slightly declined toward the end of runoff.

Iron, aluminium and potassium concentration in runoff

Generally, Al and Fe concentrations did not show any specific trend with runoff time in the three runs of different treatments (Figure 1 to 4). Overall mean concentration of Al in runoff water was higher under low rainfall intensity. Increasing the soil roughness from low to high also increased the Al concentration in runoff. Among the amendments, Al concentration was slightly higher in WTR as compared to BFS. A trend similar to Al was observed for Fe concentration. In the case of K, concentrations were higher during the first run for all the amended plots and K concentration reduced with runoff time for each subsequent run. Overall mean K concentration in runoff water did not change with change in rainfall intensity or soil roughness however in WTR amended plots K concentration was slightly higher than BFS.

Conclusion

The data showed that under the bare soil condition, the likelihood of P runoff is higher. It was observed that in control plots the DRP concentrations were lower at the start of runoff and higher at the end of rainfall. Application of soil amendments showed a reverse trend where DRP concentrations were higher at the beginning of runoff and lower at the end. Among all treatments, the DRP concentration was lowest in the WTR amended plots, followed by the control and BFS amended plots. The DRP concentrations were higher under low rainfall intensity (30 mm/h) as compared to high rainfall intensity (65 mm/h) especially under the low soil roughness condition. Lower concentration under high rainfall intensity is due to the dilution factor. WTR could be an effective amendment to reduce the P runoff from bare soils.

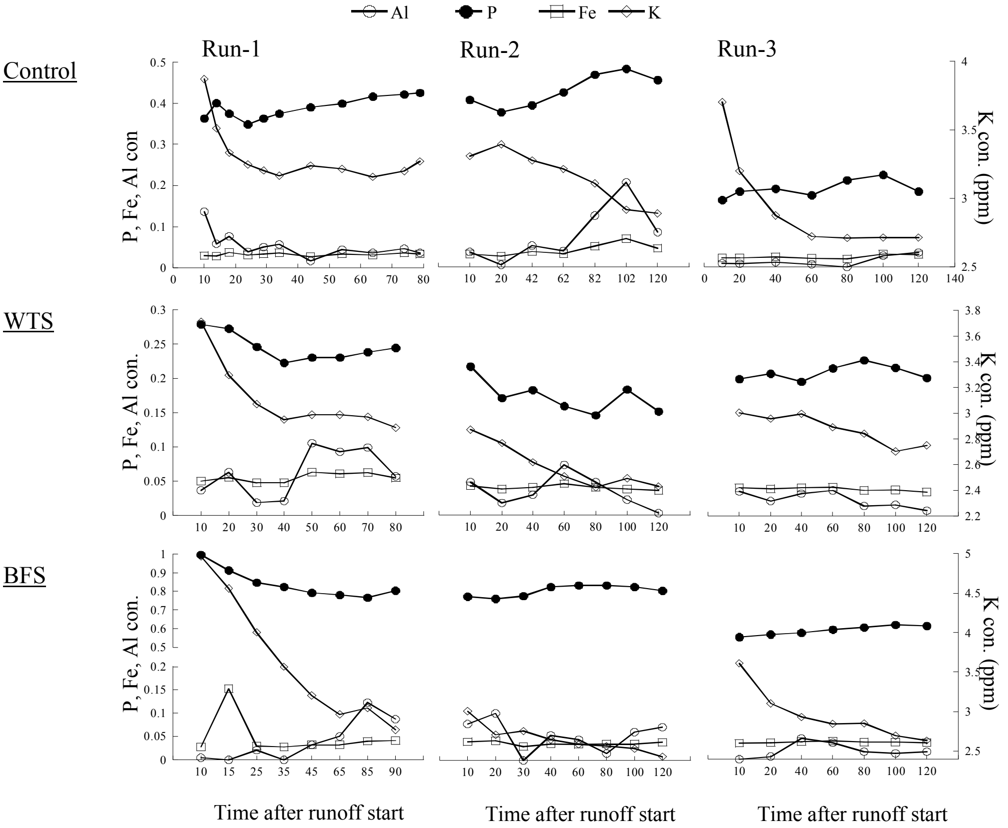

Figure 1. Effect of low rainfall intensity (30 mm/h) and low soil roughness on DRP, K, Fe, and Al concentration in runoff water

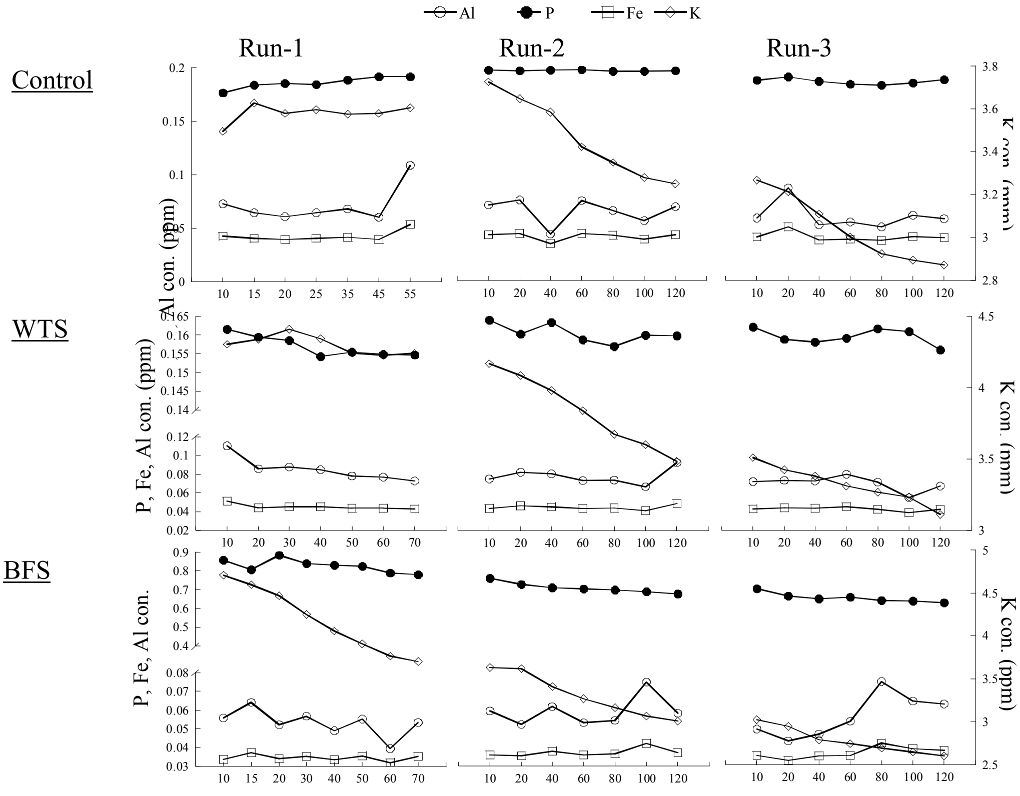

Figure 2. Effect of low rainfall intensity (30 mm/h) and high soil roughness on DRP, K, Fe, and Al concentration in runoff water.

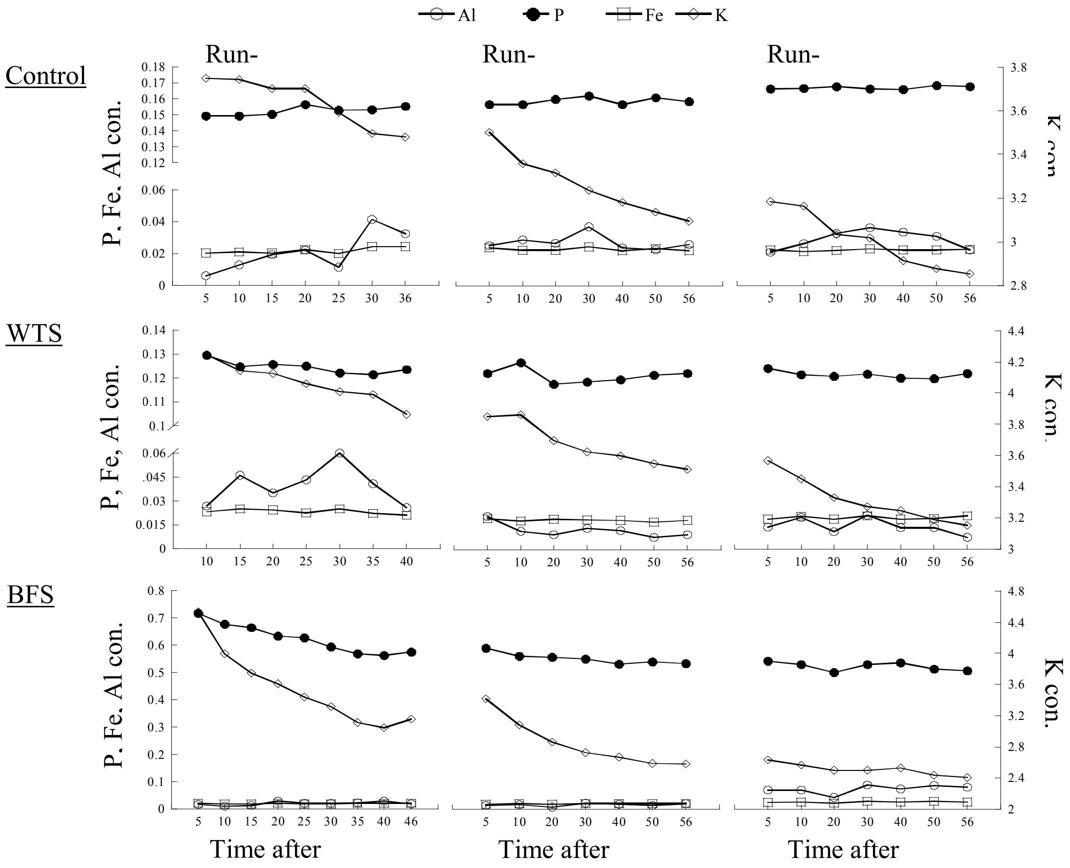

Figure 3. Effect of high rainfall intensity (65 mm/h) and low soil roughness on DRP, K, Fe, and Al concentration in runoff water

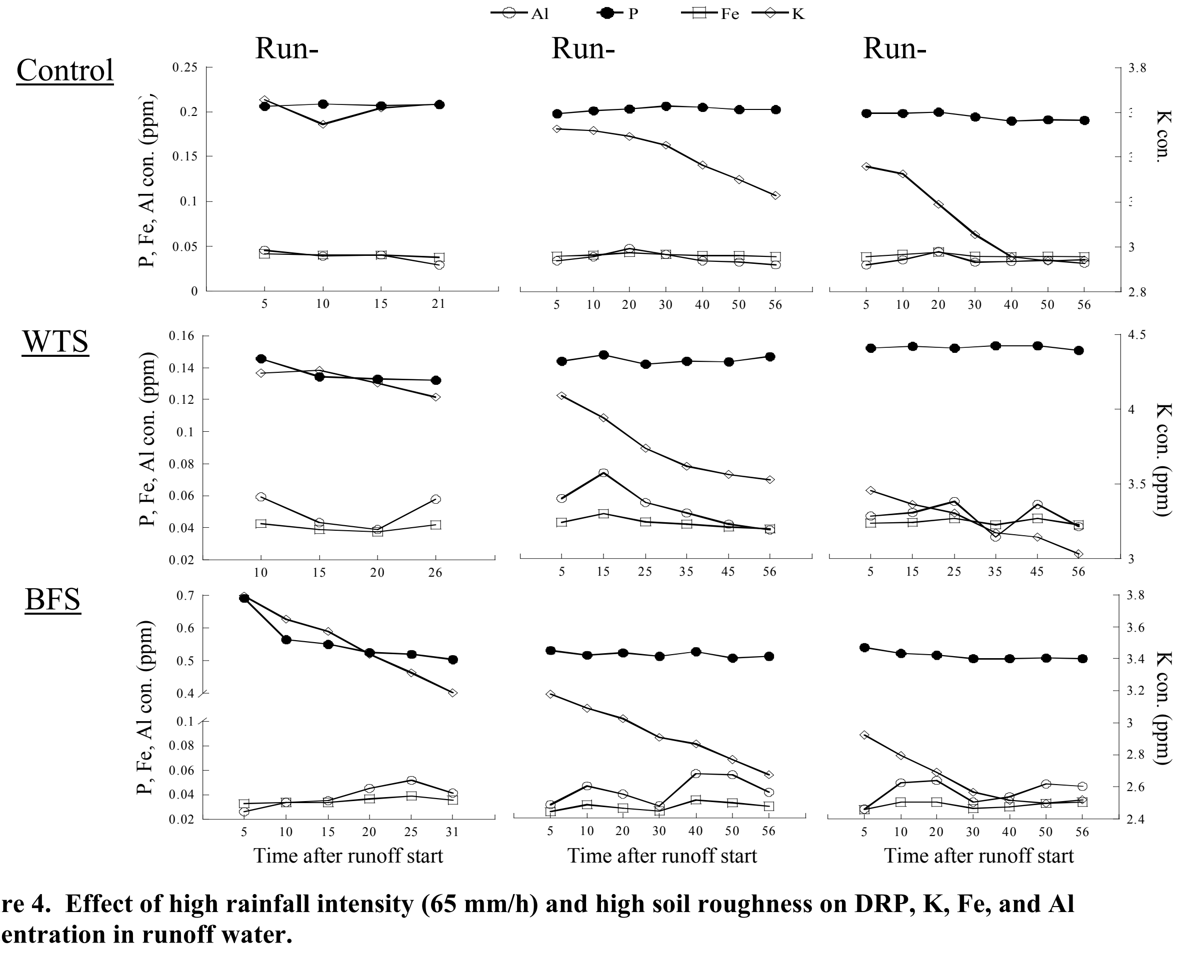

Figure 4. Effect of high rainfall intensity (65 mm/h) and high soil roughness on DRP, K, Fe, and Al concentration in runoff water.

Influence of land use systems on soil resources in northern Thailand

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Abstract

In order to investigate the link between different land use types on seasonal changes of soil properties and soil degradation, a field trial was carried out in northern Thailand, Mae Hong Son province, Pang Ma Pha district, covering five land use types namely secondary forest (SF), mixed orchard (MO), maize field (MF), upland rice field (RF) and fallow land (FL).

The measured data under different types of land use were the amount of soil translocation rate using modified Gerlach troughs. Furthermore, soil properties such as bulk density (BD), aggregate stability (SAT), infiltration rate (IR), soil texture (sand-silt-clay), total stored soil water (TSW), soil reaction (pH), extractable phosphorus and potassium (Ext.P and Ext.K), and organic matter (OM) contents were determined under each land use type.

The effects of different land use types on pH values were not different and OM values under different land use systems tended to be low. MF-B and MF-A gave the highest Ext.P and Ext.K, when compared to the other land use types. Furthermore, the highest and the lowest values of BD values were found in RF-A and SF while MF-A and FL had the highest values of IR and SAT, respectively.

Different types of land use had an essential influence on the soil translocation rate. The measurement of soil translocation showed that the lowest rate of translocation was found under SF as well as under MO or FL, while RF and MF tended to give the highest and the second high translocation rate compared to the other types of land use.

Key Words

Conventional agriculture, soil translocation, total stored soil water

Introduction

The study area is located in the mountainous Mae Hong Son province in northwestern Thailand. The traditional agriculture system in this area was based on crop rotation including fallow periods more than five years. During the last decades, land use was intensified and the fallow periods were reduced or abolished due to population growth and land pressure (Schuler 2008), causing severe soil erosion accompanied by soil losses varying from 5 – 297 t/ha/y (Vlassak *et al.* 1992, Panomtaranichagul 2005) under rainfall ranging from 1,132 – 1,723 mm/y. These soil losses are continually leading to critical deterioration in soil properties, like decreased soil quality, soil productivity and agro-ecological quality (Panomtaranichagul 2005). The purposes of this paper are (i) to present field results during 2007 – 2009, which compared the effects of land use systems on the seasonal changes of soil properties and soil water storage, and (ii) to investigate the variation of soil translocation under different types of land use.

Methods

The investigation was conducted around the villages Bor Krai and Luk Kao Lam, Pang Ma Pha district, Mae Hong Son province, Northern Thailand, at 19° 33’ N and 98° 12’E, at 600 – 1100 m above sea level. The petrography consists mostly of limestone and claystone (Schuler 2008). The most common reference soil groups in the study area are Alisols (IUSS Working Group WRB 2006). Climatic measurements for the years 2004, 2005 and 2007 showed that the mean annual precipitation ranges from 1,200 to 1,550 mm, falling mainly in June to October, with a mean annual temperature of 22°C. Five types of land use were studied in eight small catchments, (i) secondary forest (SF), (ii) mixed orchard (MO), (iii) maize field in three different sites (MF-A, MF-B and MF-C, respectively), (iv) upland rice field in two locations (RF-A and RF-B, respectively), and (v) fallow (FL). MO, MF-A, RF-A and FL are on soils from clay stone, while soils from limestone are supporting SF, MF-A, MF-C and RF-B. Measurements of soil translocation and soil properties were recorded from 2007 to 2009. The measurements were done in SF, MO, MF-A, RF-A and FL only in 2007. In 2008 and 2009, the measurements were obtained in all studied sites.

Investigation of soil translocation (soil loss and soil deposition) was measured using modified Gerlach troughs (GT) made of local bamboo. Gerlach troughs were installed in a W-formation on each field. Their quantity depended on the size of each small catchment. The soil translocation of different slope sections was determined by comparing the input of a higher GT row with the output at a lower GT row. The quantities of samples (soil sediment) taken from the upper GT row are subtracted by those from the lower GT row; then divided by the area between the two rows. In the study, soil translocation per slope segment was calculated in t/ha.

Soil sampling (composite and undisturbed soil samples) and field measurements of soil properties (physical, hydrological and chemical) at 0–200 mm, like bulk density (BD), stable aggregates based on total soil mass (SAT), steady infiltration rates (IR), soil reaction (pH), extractable P (Watanabe and Olsen 1958), extractable K (Jackson 1958; Black 1965) and organic matter (Black 1965). Moreover, total stored soil water within 1 m soil depth was taken 200 mm soil depth increments and calculated as equivalent depth of water (mm).

Results

Soil chemical properties

The average values during rainy season of soil chemical properties within 200 mm soil depth, under different land use systems showed similar trends. Values of pH were not significantly different among all land use types, FL and MO tended to give the highest and the lowest pH values, with the range from 5 – 7 (Fig 1a). OM of limestone soil tended to have higher values than in claystone soil. The mean OM values of all sites were low throughout the study period (Fig 1b). The highest and the lowest values were in MF-C (6.36 g/100 g) and RF-A (2.68 g/100 g), compared to the other land use types.

In general, seasonal changes of extractable P values increased during the study period. Meanwhile, the values of extractable K decreased dramatically from 2007 to 2009 (Fig 1c, d). MF-B and MF-A gave the highest values of extractable P (72 mg/kg) and extractable K (377 mg/kg), on the other hand, the lowest extractable P (25mg/kg) and extractable K (160 mg/kg) values were measured in SF and MO respectively.

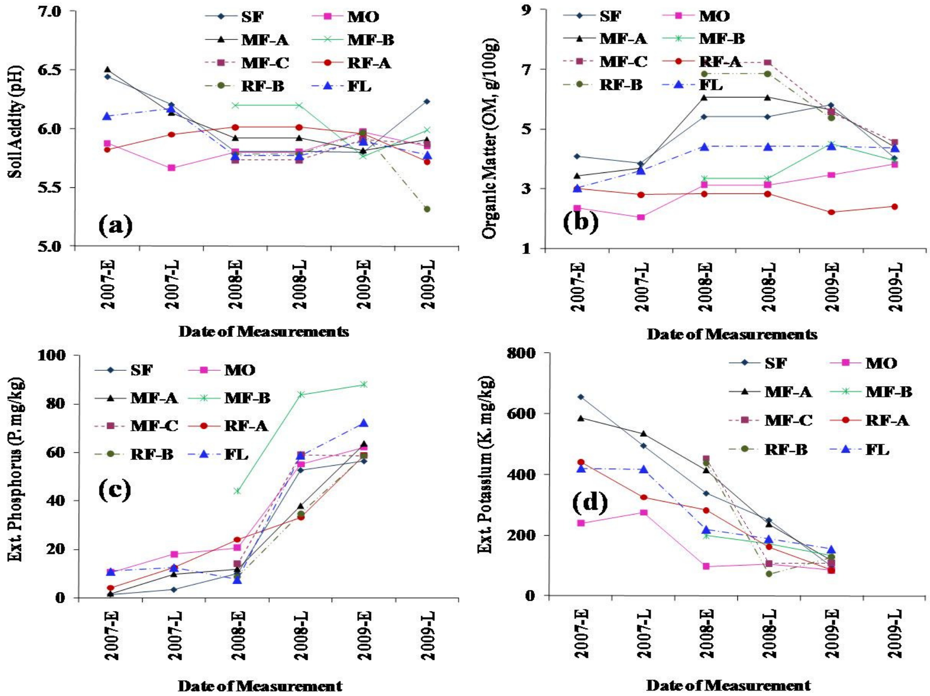

Figure 1. Average values of soil chemical properties within 200 mm soil depth, (E) = early rainy season, (L) = late rainy season, (a) soil acidity (b) organic matter (c) ext. phosphorus and (d) ext. potassium under different land use types during 18 June 2007 to 30 December 2009.

Soil physical and hydrological properties

The results showed similar changes for all soil physical and hydrological properties under the different types of land use. In general, soils from claystone (MO, MF-B, RF-A and FL) tended to give higher values of BD

than soil from limestone (SF, MF-A, MF-C and RF-B) (Fig 2a). BD tended to decrease from early of rainy season to mid of rainy season, then slightly increased to late of rainy season, while SF and RF-A showed the lowest BD (0.88 Mg/m^3) and the highest BD (1.32 Mg/m^3) values respectively. MF-A tended to have the highest IR values (88.01 cm/hr), while FL had the highest SAT (49.2%) values (Fig 2b). The average IR and SAT values were not correspondent to each other because different land use systems showed different soil structure, which govern sub- surface soil pore continuity and IR but not SAT of the surface soil.
The seasonal variations of total stored water within 1 m soil depth (TSW) under different land use types showed similar trends (Fig 2c). TSW was significantly affected by land use system. In comparison to soils from limestone, soils from claystone led to lower TSW values. SF tended to have the highest amount of TSW during 18/6/2007 - 25/5/2008, while, during 25/5/2008 – 30/10/2009, the highest values of TSW were found in MF-C and RF-B due to the highest clay content including higher IR, SAT and lower values of BD. However, during the dry season (8/9/2007 – 25/5/2008 and 17/12/2008 – 25/4/2009), SF, MO and FL had the highest values of TSW.

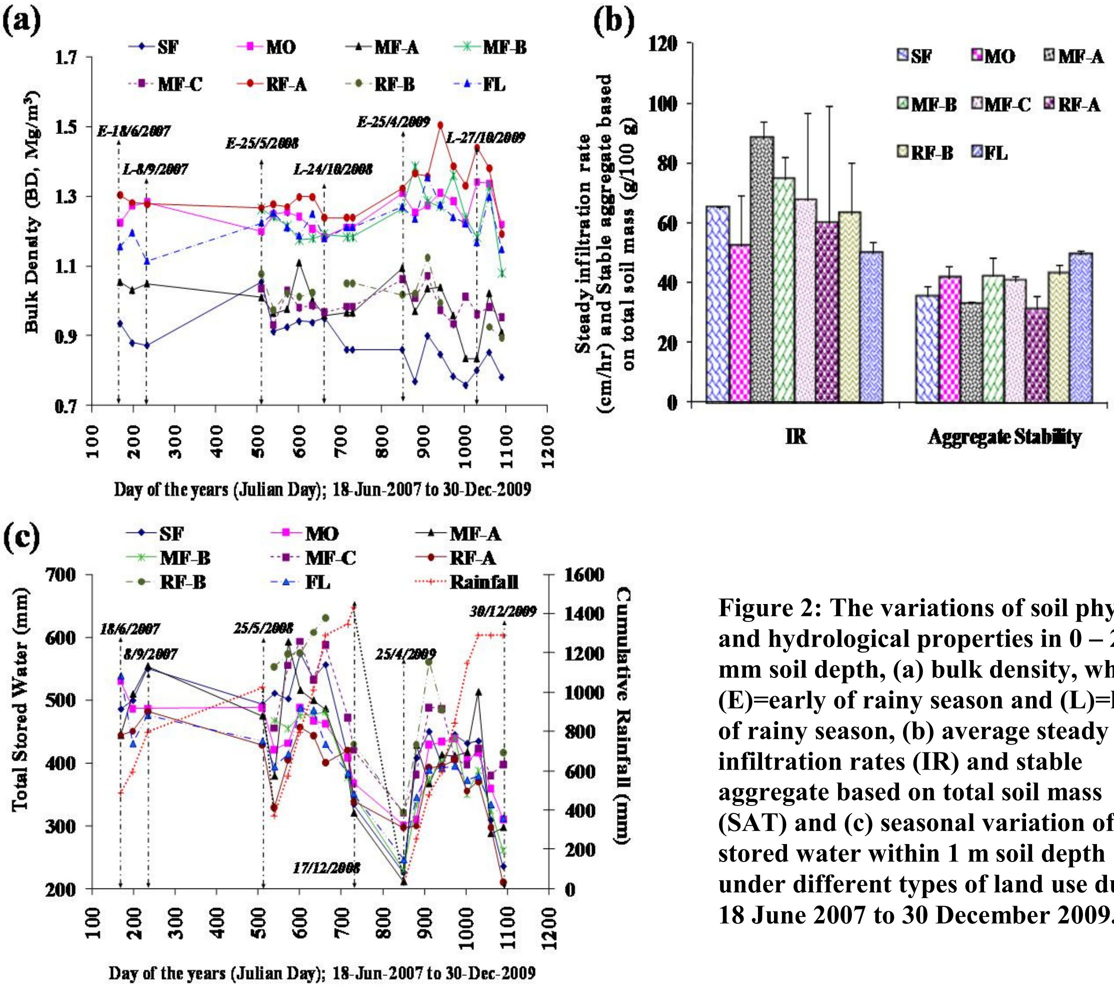

Figure 2: The variations of soil physical and hydrological properties in 0 – 200 mm soil depth, (a) bulk density, when (E)=early of rainy season and (L)=late of rainy season, (b) average steady infiltration rates (IR) and stable aggregate based on total soil mass (SAT) and (c) seasonal variation of total stored water within 1 m soil depth under different types of land use during 18 June 2007 to 30 December 2009.

Soil translocation

Calculated soil translocation rates under different land use systems during the study period displayed negative and positive values. These values were interpreted as soil deposition and soil loss (soil erosion), respectively. High translocation rates were found in MF-A, MF-B, MF-C, RF-A and RF-B, especially in RF-A, with the rates of -19.1, 23.4 t/ha and -25.2, 23.8 t/ha and -21.0, 32.1 t/ha observed in 2007, 2008 and 2009, respectively (Fig 3a-c). Soil translocation in SF was not significantly different from MO and FL. It tended to be low, although, MO produced relatively high rates of erosion in 2007 due to water supplied from the upper part. Soil translocation rates in MF-C and RF-B in 2008 were significantly lower than in 2009, because GT measurements were interrupted due to destruction by animals. Limestone soils (MF-A and MF-C) were more prone to soil erosion, than soils from claystone (MF-B) in 2008 and 2009, even though, in 2007 MF-A tended to have a high rate of soil deposition. These might be due to rainfall event different from year to year. RF-A and RF-B tended to produce the same rates of soil deposition and soil erosion in 2008 and 2009. In general, conventional agricultural practice produced remarkably high rates of soil translocation during the early rainy season caused by plot preparation, rainfall distribution, and rainfall intensity and growth stage of plant. Later in the rainy season, translocation rates decreased after the soil surface was protected by increased crop density.

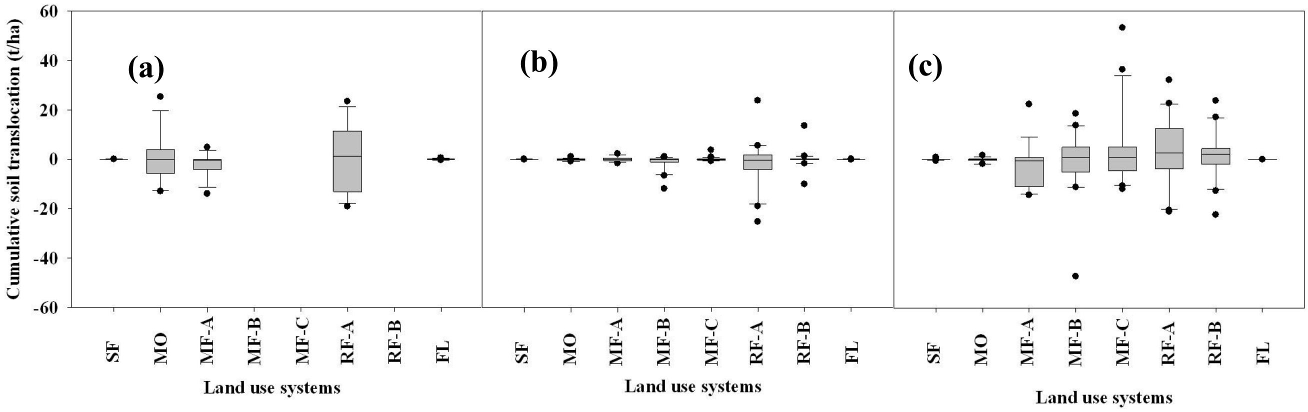

Figure 3. Cumulative values of soil translocation (t/ha) under different types of land use from May 2007 to October 2009 (a) 2007, (b) 2008 and (c) 2009.

Conclusion

The results indicated that agricultural land use types such as upland rice (RF) and maize fields (MF) tended to enhance soil erosion and poor soil properties. These may lead to degraded both soil and crop productivity. To have a sustainable land use system, SF and MO should be kept as permanent growing trees, otherwise a long period of FL must be applied. Furthermore, annually upland rice and maize should be cultivated under soil conservation practice only.

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Interactions between bio-fertilizers and the production of oats without irrigation in Chihuahua, Mexico

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Abstract

The objective of this project was to evaluate the effect of mycorrhizae and Azospirillum bacteria on the productivity of oats, with the purpose of having technology so that the producers of the State of Chihuahua, México, can combat the rural poverty with means to promote productivity. The project began during the summer of 2009, in five localities that represent the main areas planted with oats under conditions of rainfall precipitation. The climatological gradient was considered of the state of Chihuahua, studying the following locations: 1) Santa Clara, Namiquipa, 2) Campo 35, municipality of Cuauhtémoc, 3) Bachíniva, 4). General Trías, 5) El Faro municipality of Satevó. The results obtained indicate that the highest values regarding the production (5,720 kg/ha) were registered in Bachíniva Chihuahua, with the treatment: 60-40-00 of N-P_2O_5-K_2O + Micorriza INIFAP^{MR}. Significant statically differences were observed among the treatment studied, highlighting two situations: with and without chemical fertilizers. Benefits in favor of this biofertilizer in five of the five localities were registered.

Key Words

Mycorrhiza, Azospirillum, agricultural under rainfall without

Introduction

Within bio-fertilizers is a group of products based upon microorganisms that normally live in soil, but in low populations, which upon increasing their population through artificial inoculation are capable of putting at the disposition of plants important nutritive substances through their biological activity. The bio-fertilizers of direct action, like mycorrhizas, live partially or completely in vegetable tissues and therefore their action is realized in the plant and not in the surrounding area (Huerta *et al.* 2008, Martínez, and Pugnaire 2009). The bio-fertilizers with mycorrhizal fungi are beneficial products that associate with the roots of plants and contribute to their nutrition. They are present in all agricultural soils and their association with plants is beneficial as much for the plants as for the mycorrhizal fungi owing to the interchange of nutritive substances. A mycorrhiza permits a plant to increase the exploration of the root with an increase in the absorption and transport of nutrients like phosphorous, nitrogen, copper, zinc, and groundwater, endowing it with greater advantages for its development and productivity. (Rilling and Steinberg 2002; Aguirre *et al.* 2009). The objective of this project was to evaluate the effect of mycorrhiza and Azospirillum bacteria and chemical fertilizers on the productivity of oats, with the purpose of having technology so that the producers of the state of Chihuahua, Mexico, can combat the rural poverty with means to promote productivity.

Methods

Location of the area studied

The project began during the summer of 2009, in five localities that represent the principal area planted with oats under conditions of rainfall precipitation. Micorriza INIFAP^{MR} and Azospirillum bacteria were evaluated, in combination with chemical fertilizers as sources of nitrogen and phosphorus, in the districts of rural development: Cuauhtémoc (Campo 35), Bachíniva, Satevó, General Trías and Namiquipa (Santa Clara) Chihuahua, México, as can be appreciated from Figure1.

Characteristics of the study

The climatologically gradient was considered of the state of Chihuahua, Eight treatments were established on lands of cooperative farmers, considering the combinations of the chemical fertilizers and biological fertilizers. The measured variables were: height of plant, diameter of stalk/stem, number of leaves, length of root, fresh weight of the root, weight of the fresh matter, primarily in the phonological stages of tillering (the sprouting of shoots from the base of plant), flowering, physiological maturation, and harvest. The variety used was Bachíniva (elaborated by Salmerón *et al.* 2003) in a dose of 100 kg/ha. The chemical fertilizers as sources of nitrogen were urea and demonic phosphate. The statistical analyses were done through the

statistical package SAS (SAS 2001).
The economic analysis became according to the methodology (Perrin *et al.* 1979), Based on the formulation of recommendations from agronomic data. Samples were taken from soils to determine the main physical and chemical variables of the studied sites. Registry the rainfall and the slope of the land was reported. Another important part of the project was the development of courses and factories of qualification to producers of oats, technician and public generally, for which basic volume the information of the INIFAP, at national level, and the works of investigation that on the subject developed (Amado *et al.* 2000).

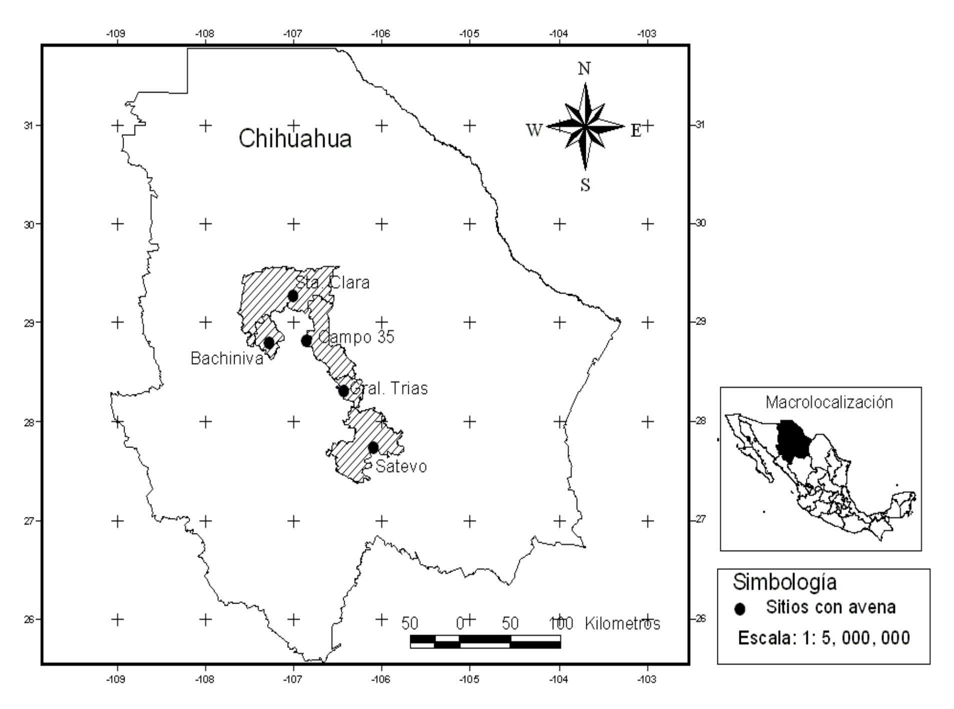

Figure 1. Distribution of the studied sites.

Results

Weight of the productions in Bachíniva, Chihuahua México.
The results obtained (Painting 1) show significant statistical differences between the treatments studied. The highest values of production was registered with the chemical fertilizer use in generally. Statistically turn out the same to apply Micorriza INIFAP^{MR}, that Azospirillum, or the combination of Azospirillum, more Micorriza, or only fertilizing chemistry. The best treatment was 60-40-0 (N P_2O_5-K_2O) + MICORRIZA - INIFAP^{MR}, with 5,720 (kg/has) yield of total dry matter. The amount of rainwater registered during the breeding cycle was of was of 269 mm, distributed of the following way: 133 mm in the month of August, and 133 mm in the month of September (Figure 2), were everything what it rained, which is equivalent to a 75% of the hydric requirements of oats. This is one of the main reasons for the low yields generally.
Painting 1. Yield of total dry matter (kg/has), using biofertilizers in Bachiniva, Chihuahua 2009.

Tratamiento	I	II	III	IV	V	Media
1.- 0-0-0 (N P_2O_5-K_2O)	4223	4015	4291	4434	4109	4214 C
2.- MICORRIZA -INIFAP^{MR}	4671	5057	4559	4660	4646	4719 BC
3.- AZOSPIRILLUM	4157	4545	4850	4809	4590	4590 BC
4.- MICORRIZA +AZOSPIRILLUM	4855	4688	4722	4411	4220	4579 BC
5.-60-40-0 (N P_2O_5-K_2O)	5706	5043	4590	5199	4644	5036 AB
6.-60-40-0 + MICORRIZA -INIFAP^{MR}	5312	5726	5562	5844	6187	5720 A
7.-60-40-0 + AZOSPIRILLUM	5809	6153	5767	5165	5413	5288 AB
8.-60-40-0 + MICORRIZA +AZOSPIRILLUM	5356	5329	5372	5112	5303	5294 AB

$F_{0.05}$ = 2.97875 ** P> F = 0.016 DMS $_{0.05}$ = 82.063 C. V. = 10.61 %

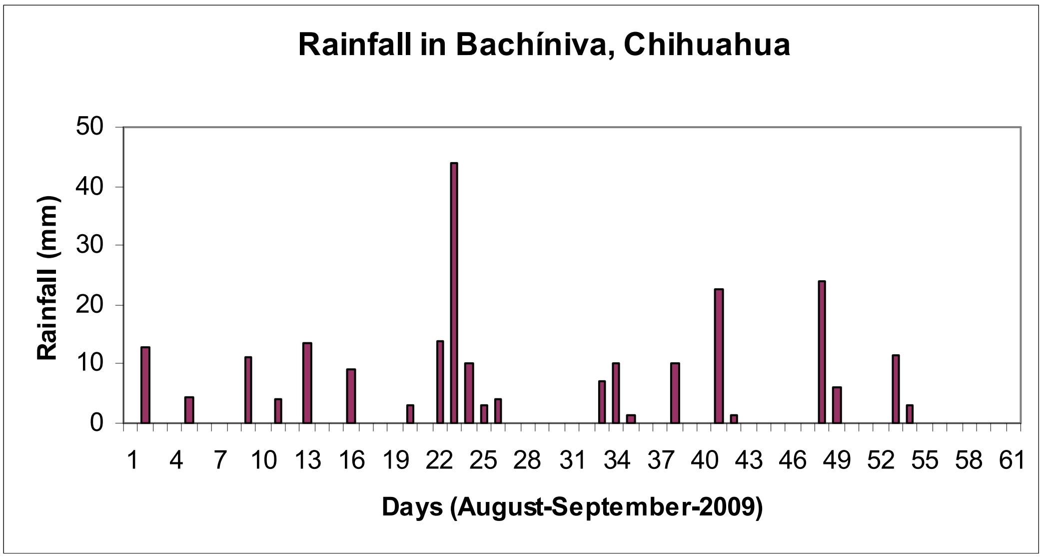

Figure 2. Rainfall in Bachíniva, Chihuahua 2009.

Conclusions

Benefits in favor of Micorriza- INIFAP^{MR} product were registered in all five localities. It was increased the production and productivity of the oats culture under conditions of rainfall. The income production index was of 2.04 in Satevo, 2.68 in Santa Clara, Namiquipa, 1.36 in Campo 35 municipality of Cuauhtémoc, 1.13 and 2.05 in General Trias.

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Long term effect of conservation tillage in a corn-oat rotation system on corn and forage oat yield in the north-central region of Mexico

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Abstract

Among the main constraints to adopting conservation tillage in the semiarid zones in Mexico's north-central region are: low acceptance among farmers, need of specialized machinery, use of herbicides, and above all, the need to utilize stubble to feed animals. The objective of this study was to assess the effect of different tillage methods in an irrigated corn-oat rotation system on corn grain, stubble, and forage oat yield. Seven tillage methods were evaluated: 1) traditional plow and disk (P+D), 2) disturbing the upper 0-4 in layer (D), 3) without disturbing the upper 0-4 in layer (ND), 4) zero tillage with 0% soil cover (ZT+0%SC), 5) zero tillage with 33% soil cover (ZT+33%SC), 6) zero tillage with 66% soil cover (ZT+66%SC), and 7) zero tillage with 100% soil cover (ZT+100%SC). In each year from 1996 to 2007, corn was sowed on the spring while forage oat was grown during the fall-winter season. Corn grain yield results showed statistical differences among treatments ($p \leq 0.05$), where ZT+66%SC was the best treatment, surpassing by 90% the corn yield registered with P+D. The statistical analysis for corn stubble yield showed no differences ($p \geq 0.05$) among treatments. With ZT+66%SC, corn stubble production was increased 3.448 ton/ha compared with that of P+D, indicating that farmers can use 2.0 ton ha^{-1} to cover at least 33% of the soil surface. Forage oat yields within the seven treatments were not statistically different ($P \geq 0.05$), but all ZT treatments were no-till seeded. Our conclusions are that corn and forage oat can be no-till seeded, increasing corn production and keeping stable production of forage oat. These results can be used to provide evidence to farmers of the benefits of adopting conservation tillage.

Key Words

Irrigation, stubble, soil cover, plow, disk, farmers

Introduction

"The truth is that nobody has ever exposed a scientific reason to till". This phrase was made by Edward H. Faulkner in the 1940s, and he was largely criticized by his contemporaries (Faulkner 1974). Conservation tillage has been proved to be an alternative to conventional tillage, but it should be validated in areas where this technique is not actually used.

With his research results, Faulkner showed that erosion, soil impoverishment, and yield reduction are the results of inadequate soil management by farmers. He challenged the technological advancement of his time, about how to produce crops, declaring that plow is and has been the main enemy of soils. He declared that by leaving crop residues on the soil surface, instead of burying them at the bottom of the plow layer, nutrients will be provided for the next crop.

In Mexico, the plow's adoption has been without any discrimination for all soil types, climates, and crops. Technical guides recommended by research, teaching, and extension institutions present the use of plow and disk as the only option of soil tillage before sowing. Besides, conservation tillage has been promoted to farmers in the last 30 years with unsuccessful results, therefore the actual area at national level with conservation tillage does not surpass 10,000 ha, which is minimal compared to that of other Latin-American countries such as Brazil, where in recent years, conservation tillage has been implemented on 15 million hectares (Claveran 2000).

Soil erosion is one of the main problems that threaten the sustainability of agriculture, so the development of sustainable production systems should be a priority, while satisfying production yield and quality necessary for consumer demands (Osuna 2000). Conservation tillage is one of the most viable options to sustain natural resources, such as soil and water, and crop yields (Angeles and Rendon 1994; Valdes *et al.* 1994). With conservation tillage, soil is protected against water and wind erosion, loss of nutrients is reduced, more soil water is available to plants, and soil organic matter, infiltration, and flora and fauna are increased

(Figueroa 1975; Figueroa 1982; 1983; Jasso 1985; Barron 1987; Osuna 1987).

Among the main constraints to adopting conservation tillage in the semiarid zones in Mexico's north-central region are: low acceptance among farmers, need for specialized machinery, use of herbicides, and above all, the need to utilize stubble to feed animals (Salazar *et al.* 1994). The use of crop residues as soil mulch is a key factor to succeed in conservation tillage, given that the greater the quantity of residues left as soil mulch, the greater the protection against erosion. The use of crop residues, especially corn stubble, to feed animals is a strong constraint in the north-central zone of Mexico, therefore development of agricultural systems with conservation tillage should contemplate diversification and increase forage production (Cabrera 1988). Finally, the conservation tillage concept, which involves the combination of zero tillage with 30% of crop residues as soil mulch, should be modified according with different agricultural systems, soils, climate and crops to avoid the same mistake made with plowing and disking as a unique option of soil till. (Sanchez 1975; Ramirez 1982). The objective of this study was to assess the effect of different tillage methods in an irrigated corn-oat rotation system on corn grain, stubble, and forage oat yield.

Methods

From 1996 to 2007, an irrigated corn-forage oat rotation system was conducted at the experimental station at San Luis, San Luis Potosi, Mexico. The site has a clay soil texture, a temperate dry climate, an annual average temperature of 16.2 ^{o}C, a frost free period from April to September, and an annual average rainfall of 210 mm (CGSNEGI 1995). Seven tillage methods were evaluated: 1) traditional plow and disk (P+D), 2) disturbing the upper 0-4 inches layer (D), 3) without disturbing the upper 0-0.10 m layer with a root cutter (ND), 4) zero tillage with 0% soil cover (ZT+0%SC), 5) zero tillage with 33% soil cover (ZT+33%SC), 6) zero tillage with 66% soil cover (ZT+66%SC), and 7) zero tillage with 100% soil cover (ZT+100%SC). A randomized block design with two repetitions was employed. Corn was seeded in the spring while oats were seeded in the fall of each year. Genotype for corn was the hybrid H-311 with 24,282 plants per acre and the genotype for oat was the variety Cuauhtemoc with a density of 100 kg/ha. A zero tillage planter with wavy disk at the front was used to cut the stubble. For fertilization and pest control, local INIFAP's recommendations were followed. Before sowing, weeds in the zero tillage treatments were controlled with Glifosfato (2 L/ha) and after planting; weeds were eliminated with the same herbicide and dose but applied with protected bell type sprayers so that the main crop was not damaged. Each crop was irrigated when 40% available soil water was registered. For irrigation, beds of 1.65 m were built, and two lines of plants were sown. Corn was sown in rows separated by 0.85 m and 0.078 m between plants. After harvest each year, corn stubble was chopped on the top of the beds leaving the different soil cover treatments (0%, 33%, 66%, and 100%). The furrows were reconstructed once a year. Four rows of oat were planted in each bed. Corn and oat forage yield was evaluated by sampling the 10.2 m^2 plots over 12 years. During the growing season of 2001, soil water content was monitored at 0-0-0.15 m and 15-0.30 m depths. Results were statistically analysed according with the experimental design employed by using the Statistical Analyses System (SAS Institute 1995).

Results

There was no statistical difference in yield among tillage treatments ($p \geq 0.05$) (Table 1). However, a trend of increasing forage oat productivity, 16% with ZT+0%SC as compared to P+D. These results were an indicator that soil was more compacted by plowing and disking than in the ZT treatments. Soil was not a limiting factor in the emergence, establishment, growth, or yield of forage oat (Table 1).

There was a yield reduction of 39 and 34% with D and ZT+100%SC in comparison with P+D. In the case of D, this reduction was explained by a compacted layer, detected at 0.20 m depth, indicating that when soil was just disked, a compacted layer developed, impeding adequate oat root development.

For corn grain yield, a statistical difference among treatments was seen ($p \leq 0.05$), where the best treatment was ZT+66%SC with 6.871 ton/ha, representing an increase of 90% in relation to P+D. In all treatments except P+D and D, there were two fewer irrigations during the corn growing season because of the stubble mulch effect. Soil water content was higher in those treatments as compared to P+D. The main reason for the different responses of corn and oat to the tillage methods evaluated were due to the higher air temperatures registered during the spring and summer months than that in the fall and winter when oat was grown. During the corn growing season, the stubble increased soil water content, resulting is higher corn yields. The higher soil water content measured in the ZT treatments compared to the P+D was the reason for the superior corn and stubble yields.

Producing higher forage yields is a challenge in the north-central region of Mexico to implement the correct conservation tillage system. Because farmers use stubble to feed to their animals, only a part of the total residue production can be used as mulch. There was no statistical difference ($P \geq 0.05$) among treatments in stubble yield. With ZT+66%SC, corn stubble production was increased 3.448 ton/ha compared with that of P+D, indicating that farmers can use 2.0 ton/ha to cover at least 33% of the soil surface.

It is important to point out the forage oat, corn grain, and stubble yields obtained with ND, because with this treatment the soil profile was not inverted, reducing production costs. This method can be used as an intermediate step between traditional and conservation tillage and it is recommended for soils with compaction and drainage problems. In this study, soil mulch was not left on the surface, so there is a question to be answered by future researchers about the effect of stubble mulch with this tillage method on corn grain and forage oat yields.

It was evident that forage availability was increased 20% with ZT+33%SC and ZT+66%SC in comparison with that of P+D. Leaving crop residues on the soil surface is justified for the reduced need for irrigation water during the cycle of corn, as well as the incremental increases in soil organic matter.

Table 1. Forage oat, corn grain, and stubble yields (ton/ha) in an irrigated corn-forage oat rotation with different soil tillage. San Luis Potosi, Mexico.

Treatments	Forage oat (DM)	Corn grain (14% M)	Corn stubble (DM)	Total forage (DM)
	--------------------ton/ ha--------------------			
Plow and disk.	5.922a	3.604c	7.035a	12.957a
Disturbing the upper 0-10 cm layer.	3.633a	4.638bc	7.592a	11.225a
Without disturbing the upper 0-10 cm layer.	6.030a	6.008ab	10.376a	16.405a
Zero tillage with 0% soil cover.	6.874a	6.743a	9.677a	16.551a
Zero tillage with 33% soil cover.	5.403a	6.414ab	10.499a	15.902a
Zero tillage with 66% soil cover.	4.888a	6.871a	10.466a	15.354a
Zero tillage with 100% soil cover.	3.894a	6.472a	10.273a	14.167a

Means followed by the same letter are not significantly different at 0.05 probability according to the Turkey test.
DM = Dry matter.
M = Seed moisture

Conclusion

Conclusions for this study were that corn and forage oat can be grown without plowing the soil, increasing corn production and keeping stable production of forage oat.

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Long-term effects of two tillage systems on soybean (Glycine max (L.) Merrill) (var. Forrest) production, soil properties and plant nutrient uptake

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Abstract

Zero-tillage (no-tillage, NT) system of crop production is attractive to farmers because of savings in fuel, labor and machinery, increased potential for double-cropping, reduced soil erosion, reduced environmental pollution, and various other advantages. To compare two tillage systems --- NT and conventional tillage (CN) --- as to their influence on soybean (*Glycine max* (L.) Merrill var. Forrest) production, soil properties and nutrient uptake, an eight-year field study was conducted at a university (USA) research farm on a Byler silt loam soil (Typic Fragiudalf). Soybean grain yields in NT were comparable to those in CN. At the conclusion of the study, organic matter (OM) levels were higher in NT. NT surface-soil evidenced a tendency to be acidic. Generally, surface accumulations of nutrients in NT did not occur. With the exception of seed nitrogen, plant nutrient-uptake remained uninfluenced by tillage; seed nitrogen tended to be higher in NT. It is estimated that with comparable soybean yields expected in NT, potential savings in fuel and labor should more than make up for the possible added equipment and chemical (herbicide) cost, and potential lime costs to ameliorate possible increased acidity in long-term no-tillage.

Key Words

No-till, conventional tillage, soil properties, nutrient uptake, soil pH, organic matter.

Introduction

Zero-tillage (no-tillage, NT) systems for crop production are generally more economical with equal, or even slightly reduced, crop yields in NT. Due to its potential for double-cropping, for reduced soil erosion, for reduced environmental pollution, and due to savings in fuel, labor and machinery upkeep, NT is generally attractive to farmers and is becoming increasingly popular. The objectives of this research were to determine the influence of two tillage systems (Conventional (CN) and no-till (NT) on: (1) the performance and yield of soybean (*Glycine max* (L.) Merrill) (var. Forrest), (2) on soil pH and soil organic matter (OM), and (3) on the dynamics of soil-nutrients, and plant-uptake of these nutrients.

Methods

Field treatments and general management

Starting in the year 1980, this field-plot research was conducted for 8 years at the Tennessee State University (USA) Agriculture Research and Extension Center ($36^0$9'9"N, $86^0$48'0"W) on a Byler silt loam soil (Typic Fragiudalf). An uncultivated old sod-field was utilized for the study in the first year. The site had a 5% land slope and is classified as moderately well-drained. Initial surface (15 cm) soil pH was 6.4. The same plots were used for eight years for the following treatments without re-randomization. No further soil amendments or lime applications were made, except the below-noted fertilizer treatments. The two tillage systems (CN and NT) were "main" plots in a split-plot statistical design with four replications. The main plots measured 29x4.6m and the subplots were 4.6x4.6m. Conventional tillage consisted of plow/disc and plant; the NT comprised of either glyphosate (N-(phosphonomethyl) glycine) or paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) application, and planting with a no-till planter. The "splits" comprised of three herbicides in the first 4 years. Five potassium (K) rates (0, 45, 90, 135, and 180 kg K_2O/ha) were superimposed on the main tillage plots during the last 4 years of the study. Fertilizers were surface-applied. 'Forrest' soybeans were planted in eight rows 51 cm apart with a 'Cole' Model 400 no-till planter.

At the end of 4th season, soil cores (20 mm diameter) were taken in 5-6 randomly chosen areas from all plots and separated into 0-2.5, 2.5-5, 5-10, and 10-15 cm depths. The cores from each plot were combined by depth. Precipitation was recorded from near-field gauges on the experimental site; temperature data reported were obtained from the National Oceanic and Atmospheric Administration's National Weather Station in Nashville, TN about 20 km away from the experimental site.

Data collection and analyses

Soybean growth characteristics (plant height, plant vigor, root-lodging, and leaf senescence were measured or visually estimated for each treatment plot. Soybean plant counts were taken at the time of crop harvest. Except in the year 1984, which was a crop failure, soybean crop was hand-harvested at maturity from the middle four rows of each plot each year of the study. Soil pH, organic matter, and soil N, P, K, Ca, and Mg, as well as seed and leaf nutrient-uptake by soybeans were determined at the end of the first four years of study. Analysis of Variance was performed to determine main plot, subplot, and interaction effects using GLM in SAS (SAS Institute 2004).

Results

Growth/Yield

The 1984 crop season was unusually dry, resulting in crop failure. The 1980, 1982 and 1986 years experienced below normal precipitation as well. These conditions were reflected in grain yields in these years (Table 1). Tillage x year interactions were insignificant for soybean plant population counts and for general plant growth characteristics (vigor, height) measured (data not shown). The grain yields in the normal and above normal rain years ranged from 2201 to 3074 kg/ha. Herbicide x tillage and fertilizer x tillage interactions were insignificant (p=0.05) for the yields; thus, these were averaged over the three herbicide treatments and the four fertilizer rates. Comparable grain yields resulted from the two tillage systems in each of the seven years (Table 1), irrespective of the climatic conditions.

Soil pH, organic matter, and soil nutrients

Soil analyses (data not reported) showed that relative to areas left in sod for 4 years, the NT plots contained slightly less N and P; had lower pH, and about equal K levels. However, the P and organic matter levels were still lower in CN compared to NT (Table 2); the K levels were comparable in the two tillage systems at the five soil depths to 15 cm. Soil pH tended to be lower in NT. Available Ca and Mg contents of the soil were also not significantly different in the two tillage systems.

Plant nutrient uptake

Of the nutrient uptake by soybean leaves and seeds, only nitrogen uptake by the seed was enhanced by NT, perhaps reflecting the influence of NT increased soil organic matter and subsequent N mineralization. No fertilizer x tillage interaction was observed as the K application rate was increased from 0 to 4 X. Increasing K rates generally increased the plant uptake of K, Ca and Mg, but not that of P.

Conclusion

In seven years of side-by-side field-plot studies comparing no-tillage and conventional tillage methods of soybean production, no-tillage was equal or superior to conventional tillage. Potential savings in fuel and labor costs should more than make up for the added costs in NT for additional herbicide and for lime (or other materials) costs to possibly ameliorate increased acidity, potentially making the NT systems more profitable for the farmer. In the case of no-tillage, the potential for reduced soil erosion and reduced pollution, with less overall operating costs, should make this method of cultivation a better choice under similar soil/climatic conditions.

Table 1. Soybean grain yields (kgm/ha) as influenced by tillage.

Year	Tillage	
	CN†	NT
1980	2138	2075
1981	2263	2201
1982	1446	1572
1983	2263	2452**
1984	***	***
1985	2452	2578
1986	1760	1949
1987	3049	3074
Average	2225	2194

†CN = Conventional tillage; NT = No-tillage; ** Statistically different at p=0.05

*** Soybean yields were not recorded in this year due to unusually dry growing season.

Table 2. Effect of tillage on soil pH, organic matter, and soil nutrients.

Soil property/ nutrient	Tillage	Soil depth (cm)					
		0-2.5	2.5-5	5-10	10-15	15-30	Average
pH	CN***	6.31	6.26A*	6.03A	6.08	6.34	6.16A
	NT	6.38	6.06B	5.88B	6.1	6.32	6.05B
AV.		6.34P	6.06Q	5.91Q	6.09R	6.33P	
Organic matter (%)	CN	1.98A	1.92A	1.65	1.51	0.85	1.57A
	NT	2.72B	1.86B	1.7	1.49	0.88	1.81B
AV.		2.36P	1.89Q	1.68R	1.50S	0.87T	
P (ppm***)	CN	111.2	128.4	135.2	139.2	72.4	119.6
	NT	124.8	140	146	151.2	80	130
AV.		118P	134.4Q	140.8QR	145.2R	76.4S	
K (ppm)	CN	74.4	48.8	36.4	32.8	25.2	44
	NT	70.4	53.6	37.2	30	25.6	43.2
AV.		72.4P	51.2Q	36.8RS	31.2ST	25.2T	
Ca (ppm)	CN	1508	1600	1576	1644	1416	1552
	NT	1760	1320	1448	1624	1392	1520
AV.		1640P	1456QR	1512PQR	1636P	1404R	
Mg (ppm)	CN	100	54	47.2	51.2	50.8	60.4
	NT	92	56.8	50	46.4	46	57.6
AV.		96P	55.4Q	48.8R	48.8R	48.4R	

* A, B=Statistically significant (p=.05) differences within each depth by the t-test; ** P, Q, R, S, T = Statistically significant (p=.05) differences between depths by the Duncan multiple range test.

*** ppm = parts per million. CN = Conventional tillage; NT = No-tillage

Table 3. Effect of tillage on plant nutrient uptake.

Nutrient	Tillage***		K-rate kgm K_2O/ha				
	CN	NT	0	45	90	135	180
					%		
Leaf N	4.4	4.6	4.5	4.4	4.3	4.6	4.4
Leaf P	0.28	0.29	0.28AB*	0.29A	0.29AB	0.29AB	0.27B
Leaf K	1.2	1.4	1.1A	1.2A	1.2A	1.4B	1.5C
Leaf Ca	1.19	1.13	1.21	1.13	1.16	1.15	1.13
Leaf Mg	0.39	0.39	0.44A	0.39B	0.36C	0.38BC	0.37BC
Seed N	6.3P**	6.5Q	6.3	6.5	6.5	6.3	6.3
Seed P	0.6	0.61	0.61	0.6	0.61	0.61	6
Seed K	1.8	1.9	1.78A	1.84AB	1.90BC	1.94BC	2.0C
Seed Ca	0.23	0.24	0.22A	0.23AB	0.25B	0.23AB	0.24AB
Seed Mg	0.2	0.2	0.2	0.20A	0.20A	0.20A	0.21B

* A, B, C = Statistically significant (p=.05) differences between K-rates by the Duncan multiple range test.

** P, Q = Statistically significant (p=.05) differences between two tillages by the t-test.

*** CN = Conventional tillage; NT = No-tillage

Acknowledgments

The financial assistance for this project was provided by the United States Department of Agriculture, National Institute of Food and Agriculture (NIFA), formerly CSREES, under the Evans-Allen program, and is gratefully acknowledged. The assistance by the crew of Tennessee State University Agriculture Research and Extension Center is also appreciated.

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Loss of Soil and Nutrient from Different Soil Managements in Highland Agriculture

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Abstract

A lysimeter study was conducted to evaluate soil and nutrient loss from soil under different managements for highland agriculture in Korea. Two treatments, use of chemical fertilizer and use of compost, were compared together with three ploughing methods. For the soil management treatments: up and down ploughing, contour ploughing, and contour ploughing with mulching were compared. No relocation was designed due to the limitation of number of lysimeter plots. The mulching material was PE film. For chemical fertilizer treatment, urea for nitrogen fertilizer, super phosphate for phosphate fertilizer, and potassium chloride for potassium fertilizer were used. Contour cropping of Chinese cabbages and potatoes reduce runoff by one half, and soil loss by one third to one fifth in comparison with the up-and down cropping. The nutrient losses were significantly reduced. Mulching in reduced soil and nutrient loss more than cabbage cropping. Since less difference of nutrient concentrations in runoff between treatments was observed than differences in total soil and nutrient losses, major difference might be depend upon nutrient loss from the soil as in cabbage cropping.

Key words

Soil loss, nutrient loss, soil management, compost, chemical fertilizer, Highland agriculture.

Introduction

Highland agriculture in Korea is widespread in the mountainous area at high altitudes > 600 m elevation, however, due to poor soil management against soil erosion, the fertile surface soil has been largely lost (Jung *et al.* 1999). To get high yields, farmers apply heavy amounts of fertilizers. The excessive nutrients might be lost together with soil particles and runoff lost from the unprotected fields, and contaminate water bodies downstream (Park 2002; 2004). This study was to evaluate soil and nutrient loss from the soil with different soil management for two vegetable crops, cabbage and potato, through a lysimeter study. The treatments included chemical fertilizers and compost, with 3 different soil management practices: up and down ploughing, contour ploughing, and contour ploughing with straw mulching.

Methods

A lysimeter study was conducted in 2004 on a experimental farm with the 13 percent slope located on Hoenggye-Ri, Daegwallyeong-Myun, Pyeongchang-Gun, Gangwon-Do at an elevation of 750 m. Table 1 shows the precipitation during the growing period at Daegwallyeong. The width of the lysimeter was 3 m, and the length was 15 m. Chinese Cabbages (*Brassica caprestris subvar. napusvar. Perkinesis:* Gangta) and potatoes (*Solanum tuberrosum*; Sumi) were planted on May 25th by the standard method of crop planting (RDA 2003). Two treatments including use of chemical fertilizer and use of compost were compared with three ploughing methods. For soil management treatment, up and down ploughing, contour ploughing , and contour ploughing with mulching were compared. No relocation was designed due to the limitation of number of lysimeter plots. The mulching material was PE film. For chemical fertilizer treatment, urea for nitrogen fertilizer, super phosphate for phosphate fertilizer, and potassium chloride for potassium fertilizer were used.

Table 1. Precipitation during the growing period of 2004 at Daegwallyeong

Precipitation (mm)						
May	June	July	August	September	October	Total
82.6	281.7	552.5	471.9	215.8	4.0	1,608.5

The application amounts of chemical fertilizers for Chinese cabbages were 250N-78P_2O_5-130 K_2O kg/ha. Half of the urea was applied as basal fertilizer, and the remaining half was applied later as additional fertilizer. Phosphate and potassium fertilizers were applied as a basal fertilizer. For potatoes rates were

$150N-158P_2O_5-130K_2O$ and all fertilizers were used as a basal fertilizer. For compost fertilizers, the mixed compost consisted of 40 % of poultry manure compost, 20 % of swine manure compost, and 40 % of swine manure-sawdust-bark mixture compost. Table 2 shows the composition of the mixed compost. The soil and runoff water through the growing season were collected at every rainfall event, and chemical properties were analysed by RDA standard methods (RDA 2003).

Table 2. Composition of the mixed compost

N(%)	P_2O_5(%)	K_2O(%)	pH(1:5)	NaCl(%)
1.25	1.79	1.05	7.8	0.13

Results

From the Chinese cabbage cropping (Table 3), the runoff from the lysimeter plot of contour cropping was one half that from the up and down cropping. The soil loss from contour cropping was one fourth of the soil loss from the up and down cropping. The total nitrogen loss from contour cropping was one thirds of the total nitrogen loss from the up and down cropping. Loss of total phosphate from contour cropping was one fifth of that for up and down cropping. Clearing, contour, cultivation + mulching reduces soil and nutrient loss

Table 3. Runoff and fertilizer loss from lysimeter plots of Chinese cabbage

Cropping		Runoff	Soil loss	Nutrient loss(kg/ha)				
Fertilizer	Plow	(m^3/ha)	(MT/ha)	T-N	T-P	K	Ca	Mg
Chemical fertilizer	Up and down	4,773	14.3	60.1	14.3	9.9	21.1	4.2
	Contour	2,086	3.8	19.5	2.9	3.6	14.1	1.2
	Contour + mulching	1,820	2.2	17.7	2.5	3.0	6.3	0.4
	Average	2,893	6.8	32.4	6.6	5.5	13.9	1.9
Compost	Up and down	4,514	15.2	65.1	12.4	9.4	14.9	3.4
	Contour	2,876	2.9	22.9	3.3	7.9	15.3	2.5
	Contour + mulching	1,613	2.5	13.5	1.9	2.1	10.2	1.1
	Average	3,001	6.9	33.8	5.8	6.5	13.5	2.3
Mean		2,947	6.8	33.1	6.2	6.0	13.7	2.1

There was, however, little difference between chemical fertilizer treatment plots and compost treatment plots. Since smaller differences in nutrient concentrations in runoff between treatments were observed than differences in total soil and nutrient loss, the major loss of nutrient may be in soil. Contour cropping of potatoes also reduced runoff by one half, and soil loss by one thirds in comparison with up-and down cropping (Table 5).

The nutrient losses were also reduced remarkably as for cabbage cropping. Mulching effects in reducing soil and nutrient loss were more distinct for potatoes than for cabbage cropping. Since there was less difference in nutrient concentrations

Table 4. Nutrient concentration in runoff for different soil management practices with cabbage cropping

Cropping		Nutrient concentration in runoff(mg/L)				
Fertilizers	Ploughing	T-N	T-P	K	Ca	Mg
Chemical Fertilizers	Up and down	4.11	0.17	1.50	2.87	0.63
	Contour	3.06	0.05	1.39	5.75	0.48
	Contour + mulching	5.32	0.11	1.42	2.80	0.16
	Average	4.16	0.11	1.44	3.81	0.42
Compost	Up and down	5.60	0.18	1.57	2.53	0.53
	Contour	4.52	0.14	2.50	4.42	0.73
	Contour + mulching	3.96	0.06	1.05	5.64	0.56
	Average	4.67	0.13	1.71	4.20	0.61
Mean		4.42	0.12	1.56	4.00	0.51

Table 5. Runoff and fertilizer loss from lysimeter plots of potatoes

Cropping		Runoff	Soil loss	Nutrient loss (kg/ha)				
Fertilizers	Ploughing	(m^3/ha)	(MT/ha)	T-N	T-P	K	Ca	Mg
Chemical fertilizer	Up and down	4,490	20.5	68.0	19.1	8.4	13.2	2.5
	Contour	2,520	6.8	23.3	5.8	4.6	5.7	1.3
	Contour + mulching	1,482	1.1	9.3	1.2	2.0	3.7	1.0
	Average	2,813	9.5	33.5	8.7	5.0	7.5	1.6
Compost fertilizer	Up and down	3,561	11.2	47.2	10.6	7.6	9.6	2.3
	Contour	1,960	4.3	20.5	4.0	3.2	4.6	1.2
	Contour + mulching	1,329	1.6	10.3	1.5	1.7	3.1	1.0
	Average	2,283	5.7	26.0	5.4	4.6	5.7	1.5
Mean		2,557	7.6	29.7	0.5	4.8	6.6	1.6

in runoff between treatments than the differences in total soil and nutrient losses, the major difference might depend upon nutrient loss in soil as in cabbage cropping.

Table 6. Nutrient concentration in runoff for different soil management practices with potato cropping

Fertilizers	Ploughing methods	Nutrient concentration (mg/L)				
		T-N	T-P	K	Ca	Mg
Chemical fertilizer	Up and down	2.96	0.24	1.09	1.11	0.27
	Contour	2.94	0.04	1.31	0.87	0.24
	Contour + mulching	3.51	0.13	1.21	2.09	0.61
	Average	3.14	0.14	1.20	1.36	0.37
Compost fertilizer	Up and down	3.99	0.14	1.51	1.23	0.42
	Contour	3.21	0.26	1.28	1.27	0.36
	Contour + mulching	3.99	0.18	1.05	0.92	0.60
	Average	3.73	0.19	1.28	1.14	0.46
Mean		3.44	0.17	1.24	1.25	0.42

From another monitoring survey carried by Park (2008), BOD loads from a catchment in the highland area during the rainy period in the cropping season were 3 times to the loads during the non-rainy period.
The estimated T-N pollution loads were 0.290 ton/day and 0.298 ton/day for non-rainy periods and 1.180 ton/day and 1.033 ton/day for rainy periods. The estimated T-P pollution loads were 0.223 ton/day and 0.155 ton/day for non-rainy periods and 0.812 ton/day and 0.373 ton/day for rainy periods. The T-N and T-P loads were 4 times those in non-rainy periods. Proper management including contour cropping to reduce soil erosion and N and P loads are urgently needed for highland agriculture.

Conclusion

The experimental results showed that contour cropping could reduce soil erosion and nutrient loss, regardless of crops and fertilizer use pattern. Contour cropping of Chinese cabbages and potatoes reduced runoff by one half, and soil loss by one third to one fifth in comparison with the up-and down cropping. The nutrient losses were also reduced remarkably. Mulching reduced soil and nutrient loss especially for in potatoes cropping. Proper managements including contour cropping to reduce soil erosion and N and P loads is urgently needed for highland agriculture.

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Maize productivity as influenced by organic inputs and mineral fertilizer in a Nitisol soil in Meru South District

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Abstract

Declining land productivity is a major problem facing smallholder farmers in Kenya today. This decline primarily results from a reduction in soil fertility caused by continuous cultivation without adequate addition of external nutrient inputs. Improved fertility management combining organic and mineral fertilizer inputs can enable efficient use of the inputs applied and increase overall syste productivity. Field trials were established at two sites with different soil fertility status in Mucwa with the aim of determining the effects of various organic sources (tithonia, mucuna, calliandra and manure) and their combinations with mineral N fertilizer on maize grain yield and soil chemical properties. Sole tithonia and sole calliandra treatment generally recorded the highest maize grain yields for Mucwa poor and Mucwa good sites, respectively. Generally the maize grain yields were lower in the treatments with fertilizer alone compared to the treatments with organics in the two sites in the seven cropping seasons. There was a general decline in soil chemical properties over the seasons, even with the seasonal input application in both sites. Manure was superior in terms of improving soil chemical properties for instance, it supported an increase in soil pH, magnesium, potassium, calcium and nitrogen.

Key words

Manure, tithonia, soil pH, Soil organic carbon

Introduction

The central highlands of Kenya cover both areas with high potential for crop production on inherently fertile nitisols and drier areas with lower potential on lighter, fragile soils, prone to quick degradation. The soil fertility in the central highlands has declined over time, with an annual net nutrient depletion exceeding 30 kg N (Smaling 1993) as a result of continuous cropping with inadequate nutrient replenishment (Mwangi *et al.* 1998). In most smallholder farms, these deficiencies could be replenished through the use of mineral fertilizers and cattle manure. However, few farmers can afford mineral fertilizers and farmer using them hardly ever use the recommended rates (60 kg N/ha) for the area, with most of them applying less than 20 kg N/ha (Adiel 2004), on the other hand the use of manure is also limited by its low quality (Kihanda 1998). As a result, soil fertility has continued to decline as has the productivity of the land (Adiel 2004). Trials using organic and mineral fertilizer inputs were established in 2004 with the main objective of addressing the decline in soil fertility. The study aimed to determine the effects of different organic sources and combinations with mineral fertilizer inputs on maize grain yield and soil chemical properties.

Materials and Methods

The study was conducted in Meru South District in the central highlands of Kenya. In Meru South the experiment was conducted in Mucwa (00º 18' 48.2" S; 37º 38' 38.8" E) which is located in the upper midland with an altitude of approximately 1373 m above sea level. The soils are Rhodic Nitisols (Jaetzold *et al.* 2006), which are deep, well weathered with moderate to high inherent fertility. The study was conducted in two farms one that had relatively good soils (in terms of soil pH, total soil carbon, and available P) and another that had poor soils. The rainfall is bimodal, falling in two seasons, the long rains (LR) lasting from March to June and short rains (SR) lasting from October to December. The area receives an annual mean rainfall of 1400 mm.

The experiments were established in Mucwa good and poor sites and were laid out as a randomized complete block design replicated thrice with the plots measuring 6 x 4.5 m. The test crop was maize (*Zea mays* L, var. H513) planted at a spacing of 0.75 and 0.5 m inter- and intra-row, respectively. External nutrient replenishment inputs were applied to give an equivalent amount of 60 kg N/ha (this is the recommended rate of N to meet maize nutrient requirement for an optimum crop production in the area) with the exception of the herbaceous legume treatment where by the amount of N was determined by the biomass harvested and incorporated in the respective treatments. P was applied in all plots at the recommended rate (60 kg P/ha) as triple super phosphate (TSP). Maize grain and stover was harvested at maturity from a net area of 21.0 m^2 (out of the total area of 27 m^2). Maize grains were dried and yield was expressed in terms of dry matter content.

At the beginning and end of the experiment, soil samples were collected at 0-15 cm. The soil samples were analysed for soil organic carbon, total nitrogen, available P (Olsen), Ca, Mg and K, and pH using standard methods (Anderson and Ingram 1993). Data was subjected to analysis of variance using Genstat software. The means were separated using Least Significant Differences of means (LSD at $p < 0.05$). To determine changes in soil chemical properties during the two year cropping period, *t* tests comparing means between the two sampling periods (October 2004 and August 2006) were done.

Results and Discussions

Maize grain yield

For Mucwa good and poor sites there was a significant ($p < 0.001$) effect of seasons on maize grain yield. There was a significant interaction between the sites during the SR 04, LR 06 and LR 07 with $p < 0.001$, $p = 0.021$ and $p < 0.001$ respectively. The treatments with sole organic and organic integrated with mineral fertilizers increased the maize grain yield in comparison to the recommended rate of sole mineral fertilizer (60 kg N/ha) at Mucwa good site.

Table 5. Maize yields (t/ha) under different treatments during seven cropping seasons at Mucwa good and poor sites, Meru South District

Treatment	SR 04	LR 05	SR 05	LR 06	SR 06	LR 07	SR 07
Mucwa good							
Calliandra	3.39	5.21	4.75	3.70	4.90	5.38	6.17
Calliandra + 30 kg N/ha	2.01	5.39	2.93	2.60	3.71	3.29	4.92
Mucuna	0.66	6.47	3.04	2.23	2.82	4.45	4.75
Mucuna + 30 kg N/ha	0.82	6.09	3.00	2.67	3.80	4.50	6.40
Tithonia	2.97	6.04	3.07	2.86	3.93	4.03	3.4
Tithonia + 30 kg N/ha	1.85	6.05	3.51	2.75	3.03	3.19	5.1
Manure	1.35	5.45	3.51	2.28	4.38	4.06	5.6
Manure + 30 kg N/ha	1.01	5.89	2.97	0.79	3.00	3.33	3.66
Fertilizer (60 kg N/ha)	1.35	5.84	3.02	1.69	3.76	3.30	4.09
Control	0.64	3.32	1.62	0.34	0.84	1.04	1.24
SED	0.16***	0.39***	0.86*	0.38***	0.67***	0.79**	1.03**
Mucwa poor							
Calliandra	2.10	5.57	2.60	2.91	3.42	3.50	6.26
Calliandra + 30 kg N/ha	2.82	4.80	1.74	1.08	2.36	2.64	5.22
Mucuna	0.28	4.79	1.44	1.05	1.67	2.39	3.0
Mucuna + 30 kg N/ha	0.21	5.88	2.65	2.74	3.32	4.39	4.8
Tithonia	2.88	6.65	2.80	3.06	4.17	3.85	5.6
Tithonia + 30 kg N/ha	2.34	5.00	2.18	1.78	3.11	2.53	3.67
Manure	0.73	5.85	2.76	1.80	4.66	2.81	4.11
Manure + 30 kg N/ha	1.17	4.79	1.70	0.73	2.39	2.16	4.15
Fertilizer (60 kg N/ha)	0.76	4.27	1.68	0.52	2.87	1.00	3.39
Control	0.76	2.35	0.76	0.54	0.50	0.63	1.41
SED	0.53***	0.76**	0.53*	0.52***	0.74***	0.58***	0.72***

*, **, *** = significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively, SED = Standard error of differences

At Mucwa poor site, the treatments with sole organics performed better than the ones with integration of organic and mineral fertilizer across the seven seasons (Table 5). The treatments with sole organics and integration of organics with mineral fertilizers increased the maize grain yield in comparison to the control during all the seasons in Mucwa poor site. The treatments with sole organics and organics integrated with mineral fertilizers increased the maize grain yield in comparison to the recommended rate of the sole mineral fertilizer (60 kg N/ha).

The application of organic alone or in combination with mineral fertilizers led to increased maize yield compared to the control. Several authors have reported increased yields as a result of applying tithonia, calliandra and manure inputs in other areas (Kimetu *et al.* 2004; Mucheru-Muna *et al.* 2007). In Western Kenya, yield increases of up to 200% was reported following application of tithonia biomass (Jama *et al.* 2000).

Generally, the maize grain yields were lower for the treatments with fertilizer alone compared to treatments with sole organic or organic combined with mineral fertilizers in both sites and the seven cropping seasons. Mtambanengwe *et al.* (2006) reported a yield increase of 104% following manure application against sole fertilizer. This implies an increased nutrient recovery in the sole organic and organic plus mineral fertilizer treatments compared to sole mineral fertilizer treatment.

Soil chemical properties

At Mucwa good site, the soil pH, Ca, Mg, and K, were not statistically different ($p < 0.05$) in 2004, however, in 2006 they were statistically different (Figure 1). Soil carbon decreased in all the treatments during the two years of continuous cultivation. At Mucwa poor site, in 2004 soil pH, Ca, Mg, K, exchangeable P, total N, and organic carbon were not significantly different ($p < 0.05$) between treatments while in 2006, soil pH, Mg, and K were significantly different between treatments. Soil pH increased in the sole manure treatment ($p = 0.013$).

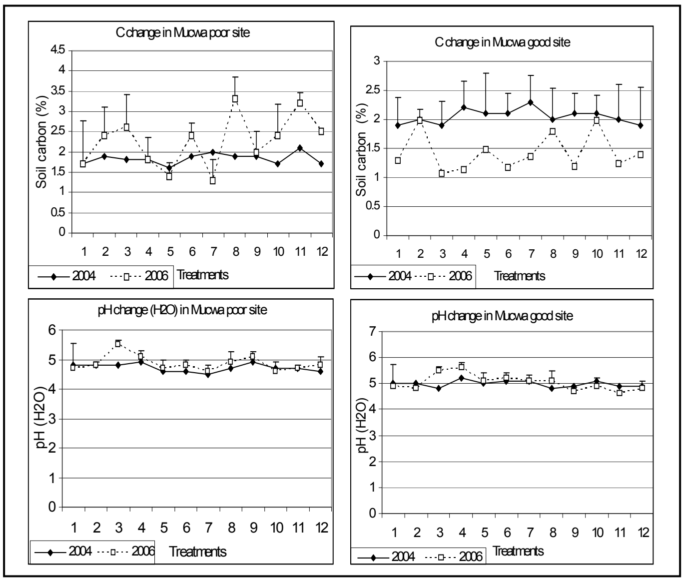

Figure 1. Carbon and pH changes for Mucwa good and poor sites between 2004 and 2006

The significant pH increase for Mucwa good and poor sites with manure treatment corresponds with the findings by Bayu *et al.* (2005). It is well documented that OH^- produced by lime raises soil pH, whereas the increase in soil pH due to green manure is less obvious and open to discussion (Hunter *et al.* 1997). It has been proposed that ligand exchange reactions between manure-derived organic anions and terminal OH of the soil solid phase are involved in, or even responsible for, such pH increases (Hue 1992). The pH increment in manure treatment could also be explained by the high increment in the concentration of base forming cations (calcium, magnesium and potassium). Any process that will encourage high levels of exchangeable base forming cations will contribute towards a reduction in acidity (Brady 1990) as was the case in this study.

Soil carbon decreased for most of the treatments at Mucwa good site. The reduction in C levels could be attributed to rapid decomposition rates in the area. Soil carbon increased with the application of manure as opposed to the other treatments. The increase of soil organic carbon in the manure treatment could be as a result of lower quality (low N and high ash content) and lower decomposition rates compared to the other organic materials. In addition, the organic carbon of manure is usually more humified and consequently, more resistant to mineralization (Saviozzi *et al.* 1999).

Conclusions and recommendations

Generally the treatments with application of organics resulted in higher maize grain yields compared to the treatments with sole mineral fertilizer, demonstrating the superiority of the organics in yield improvement due to their beneficial roles other than the addition of plant N as in the case of mineral fertilizer treatments. The seasonal addition of organic and mineral fertilizers to the soil was not able to prevent the decline in soil fertility due to cultivation. The treatments that had very high maize grain yields did not lead to improved soil fertility. This therefore means that there is a need for tradeoffs when selecting the treatment to apply to the soil.

Acknowledgements

The authors wish to thank Vlaamse Inter-Universitaire Raad (VLIR) and International Foundation of Sciences (IFS) for providing financial support for the field experimentation.

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Mechanisms of water erosion in a partially melted, frozen Andisol

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Abstract

Partially melted seasonal frozen soil is susceptible to water erosion. In this study, artificial rainfall was applied to a partially thawed soil and the effects of soil physical conditions on erodibility of partially thawed Andisol was measured. An Andisol from a mountain range area was used. The soil was packed into a plastic box to form an 8-cm thick subsoil. The packed soil was kept in a refrigerator at -30°C for one night to form the frozen subsoil. Before the rainfall, disturbed soil was laid over the frozen subsoil to form 2-cm thick unfrozen layer as a model for a thawing surface soil. During the rainfall experiment, runoff, eroded soil, seepage from outlets at front wall of the down slope end of the box was sampled periodically. In the early stage of the rainfall, impermeable frozen subsoil was the reason for enhanced runoff and soil loss, while surface sealing was the main cause of the runoff during latter half of the rainfall event. Seepage from above or through the frozen subsoil suggested saturation of near surface unfrozen soil, and soil loss was significantly large for the same period, even though the runoff rate was similar through the rainfall experiment.

Key Words

Freeze-thaw, buoyancy force, suction, effective stress.

Introduction

Soil erosion depresses productivity of agricultural lands. An estimate suggests that agricultural production has been reduced 10% worldwide by soil erosion (Lal 1998). In early spring, partially melted frozen soils are subject to accelerated water erosion. In the USA, about 4.2 million km^2 of agricultural lands are affected by soil freezing and thawing (Formanek *et al.* 1990). Similar problems are seen in Norway, Canada and Japan. Additionally, winter irrigation, which is expected to store water as ice, is one of the conventional practices in inland semi-arid regions. This may have a side effect of preventing infiltration of rainfall in early spring. It is still not clear if during the freezing process; aggregate disintegration or reduction of infiltration contributes more to inhibiting infiltration and increasing soil loss. Orradottir *et al.* (2008) discussed changes in infiltration of Andisols in response to vegetation and snow cover. However, it is still not known how the initial moisture condition affects infiltration, runoff and soil loss of partially frozen Andisol soils. The main objective of this study is to clarify the effect on initial, pre-freeze, and moisture condition on runoff and soil loss from a frozen Andisol.

Material and Methods

An Andisol from Tsumagoi, Gunma, Japan was used. Tsumagoi is a mountain range of central Japan that lies at an altitude of 1200m. Average daily temperature from December to February is below 0°C. Texture of the soil was silty clay loam, and loss on ignition was 16%. Soil had natural water content was sieved through 2-mm mesh screen and kept in a plastic bag until the experiment. The soil was packed into a 0.1m (W) × 0.1m (D) ×0.5m (L) plastic box to form 8 cm thick subsoil. Initial, pre-freeze, volumetric water content of the subsoil was 20, 40 and 60%, respectively. The packed soil was kept at -30°C overnight to form the frozen subsoil. Before the rainfall, 2-cm of unfrozen soil was laid over the 8-cm frozen subsoil to form unfrozen layer as a model for a thawing surface soil. Packing dry bulk density of surface and subsoil was 0.6 and 0.7 Mg/m^3, respectively. Slope of the soil box was 8% and experiments were done in duplicate for each condition. Rainfall was applied by using the Norton ladder-type rainfall simulator that was set 2.1m above the soil box. Veejet 80100 nozzle with 41kPa water pressure was employed. Rainfall intensity was 42 ±2 mm/h. Raindrop size distribution produced by the same nozzle with a similar water pressure was similar to a natural rainfall, and kinetic rainfall energy was estimated to be 90% of the natural rainfall (Meyer and Harmon 1979). Four collection troughs were attached down slope end of the box, and drainage, discharge and eroded soil were periodically sampled. Thermocouples were inserted 2.5 and 5 cm from a side wall and 2.5, 5.5 and 8.5 cm in depth near the down slope end of the box, and soil temperature during rainfall event was monitored.

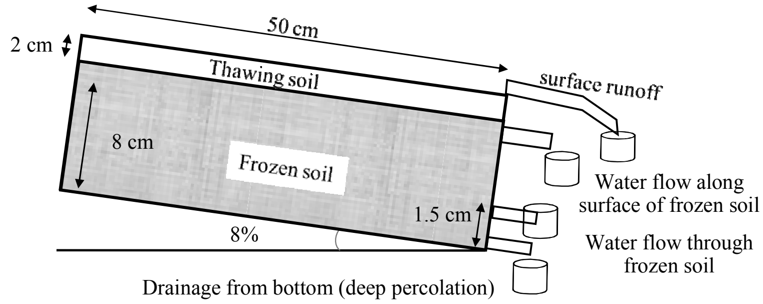

Figure 1. Outline of soil box and collector troughs.

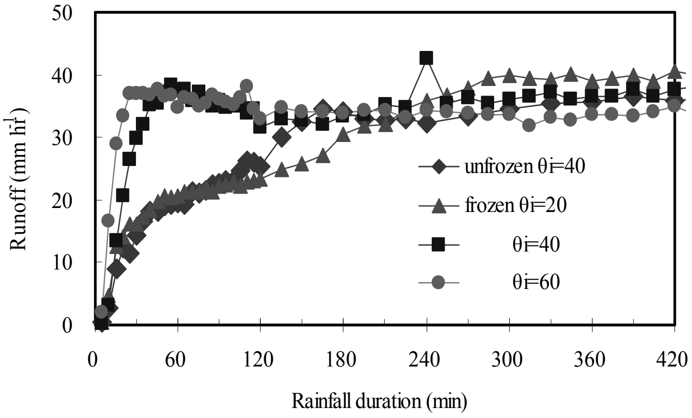

Figure 2. Runoff from soil with and without frozen subsoil with different initial volumetric moisture or ice fraction. Legend denotes treatment and initial volumetric moisture or ice fraction of the subsoil. Packing dry bulk density of the subsoil was 0.7 Mg/m^3.

Results

Runoff with and without frozen subsoil

Figure 2 shows runoff from soils with or without frozen subsoil. Initial volumetric water content was assumed equivalent to initial ice fraction. Subsoil ice fraction of 20% had a similar runoff as the treatment without frozen subsoil, while treatments with higher initial ice fraction of frozen subsoil, 40 and 60%, gave quick runoff initiation, and more than 80% of rainfall was discharged as runoff. The high initial ice fractions, 40 and 60%, also caused seepage from outlets connecting frozen subsoil layer. The seepage was small, but continued 2 hours from the beginning of the rainfall (Figure 3). This suggested soil above the frozen subsoil was saturated during the early stage of the rainfall, and runoff of this period was due to impermeable frozen subsoil. Soil that had no frozen subsoil and initial ice fraction of 20% showed less runoff for the same rainfall duration due to infiltration. After 2 hours of rainfall when melting frozen subsoil was expected, runoff was similar for all the subsoil conditions. From the observation, surface seal formed by raindrops, instead of the frozen subsoil, dominated soil and water dynamics for latter stage of the rainfall event.

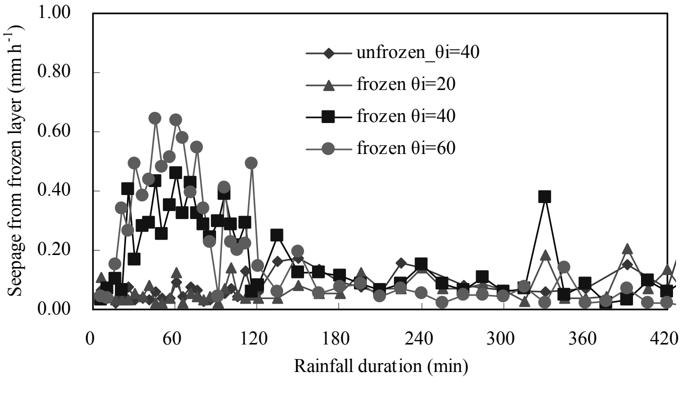

Figure 3. Seepage above and through frozen subsoil. Legend denotes treatment and initial volumetric moisture or ice fraction of the subsoil. Packing dry bulk density of the subsoil was 0.7 Mg/m^3.

Soil loss during rainfall event

Soil loss rate showed similar feature with the runoff. Subsoil ice fraction of 20% resulted to show similar soil loss rate to the one without frozen subsoil while soil had frozen subsoil of higher initial ice fraction gave high soil loss rate at the beginning of runoff. Soil loss rate was significantly high when seepage from the down slope end was observed (Figure 3), and 2 hours of rainfall and later, soil loss rates became similar for all the subsoil conditions (Figure 4). This suggested that soil becomes to be susceptible water erosion when permeability of frozen subsoil is low enough to cause water saturation near surface soil. However, when hydraulic characteristics of surface seal dominate runoff and infiltration, soil loss seems to be controlled by the physical property of the seal.

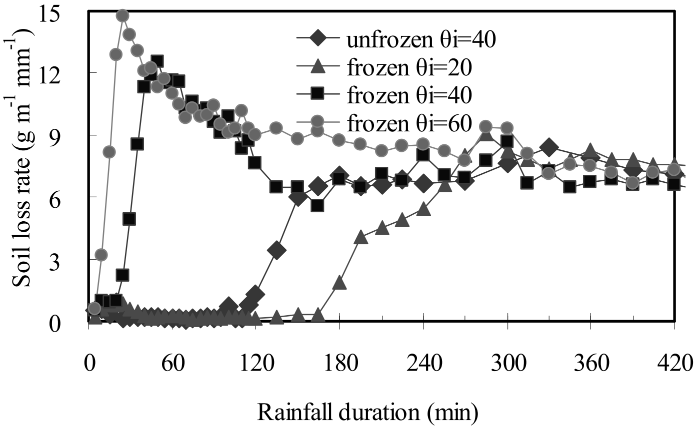

Figure 4. Changes in soil loss with and without frozen subsoil having different initial volumetric ice fraction. Legend denotes treatment and initial volumetric moisture or ice fraction of the subsoil. Packing dry bulk density of the subsoil was 0.7 Mg/m^3.

Mechanisms of soil loss from partially thawed soil

Froese *et al.* (1999) and Cruse and Larson (1977) suggested that from the point of view of soil strength, detachment of particles from soil surface by runoff could be affected by soil shear strength, and therefore by buoyancy force under water saturated condition and matric potential of unsaturated soil water. When surface seal forms, water pressure gradient may form across the seal and the soil beneath, and pore water pressure at shallow depth became negative (Nishimura *et al.* 1993; Froese *et al.* 1999). For example, saturated hydraulic conductivity of surface crust formed on Yamanashi Andisol, Japan was 3 mm/h (Nishimura *et al.* 1993) and smaller than the average percolation rate under shallow surface runoff during late stage of the rainfall event, 5 mm/h, in presenting study. This could cause negative pore water pressure below the seal. Shift of mechanism of producing runoff such as impermeable subsoil of high initial ice fraction frozen subsoil to low permeable surface seal, could be a reason of different soil loss late rate (Figure 4) with similar runoff rate (Figure 2) from soils with different extent of freezing.

Conclusion

Water dynamics in partially frozen soil under rainfall changed depending on the extent of thawing. When the frozen soil layer inhibits infiltration, its low permeability may be the major cause of runoff, while a frozen soil that has partially melted or has enough permeability so that surface seal formation reduces infiltration and produces runoff. Temporal variation in soil loss rate with almost steady runoff suggests soil loss responses to a mechanisms producing runoff. When subsoil with low permeability is the major reason for runoff, buoyancy forces acting on soil particles at the surface saturated region enhances soil loss, while suction of soil water across the surface seal may increase effective stress of surface soil and therefore strengthen the surface soil and reduces erosion. From the results, it is recommended to farmers, if possible, to prevent high moisture condition at initiation of seasonal soil freezing. Fall or winter irrigation to store water in soil for spring cultivation is not recommended from the point of view of erosion of thawing soils.

Acknowledgements

This work was supported partly by Grant-in-Aid for Scientific Research (A), 20248025, and (B), 21380142 from Japan Society for the Promotion of Science. We appreciate Drs. Darrel Norton and Chi-Hua Huang of the USDA-ARS National Soil Erosion Research Laboratory for construction of rainfall simulator, and Mr. Magome for sampling the soil used in this study.

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Nutrient deficiencies limiting the growth of sweetpotato vines on important soil types in the highlands of Papua New Guinea

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Abstract

Declining soil fertility is threatening the productivity of sweetpotato in the highlands of Papua New Guinea (PNG). A survey of sweetpotato gardens (SMCN/2005/043) identified K, S and P deficiencies as the main nutritional limitations on tuber production in the region. A pot experiment was conducted to evaluate how sweetpotato vines, propagated on three important soil types (Humult, Aquept and Aqoll), are affected by sequentially omitting 13 nutrients (N, P, K, Ca, Mg, S, Fe, Bo, Zn, Mn, Cu, Mo, Ni) from fertiliser applications. On the Humult, only the minus Mo treatment produced significantly less shoot yield than the all nutrient control (ALL), but symptoms of S deficiency were also present in plants on the minus S treatment. On the Aquept, the minus N, P, Ca, S, B and Mn treatments had significantly less shoot yields than the control, but the minus S and N treatments were lowest yielding, and the S deficiency being clearly manifest. On the Aqoll, the minus N, P, S, Mn, Zn, Mo and Ni treatments had significantly lower shoot yields than the control, and again the minus S treatment produced the lowest yield. On all three soils, vine yields in the minus K treatments were not significantly less than those in the ALL, even though the concentrations of K in soil were very low (0.02 meq/100g). It was concluded that the early stage of vine propagation is probably less K-demanding than the tuber production stage in mature crops.

Key Words

Sweetpotato, nutrient deficiencies, vine production, sulfur, potassium, molybdenum

Introduction

Sweetpotato (*Ipomoea batatas*) is the staple food crop in the PNG highlands. Declining crop productivity, however, appears to be threatening the sustainability of sweetpotato-based farming systems within the region, a probable cause being the exhaustion of soil nutrient reserves in continuously cultivated sweetpotato gardens. To assess the extent of the problem, an ACIAR funded survey of sweetpotato gardens (SMCN/2005/043) was conducted across four highlands provinces and information on soil and crop variables was obtained for old gardens (cultivated over many seasons) and new gardens (newly brought into cultivation) on soils of volcanic and non-volcanic origin (Kirchhof 2009). Crop leaf nutrient data collected in the survey suggested that K deficiency was the primary cause of poor crop production in almost a third of sweetpotato gardens. Phosphorus deficiency was also a problem on volcanic soils, and S deficiency on non-volcanic soils (Bailey *et al*. 2009). A follow-up study was planned to acquire more detailed information on nutrient dynamic processes in sweetpotato cultivation systems, and to use this information to develop optimal nutrient management regimes capable of sustaining sweetpotato production on three key soil types. The preliminary phase of the follow-up study involved nutrient omission trials. These were used to evaluate how the growth of sweetpotato vines, propagated on three important soil types were affected by sequentially omitting a range of macro and micronutrients from fertiliser applications.

Methods

Soils

Soils were collected from the A horizon at three sites: (**1**) Aiyura, (**2**) Kondiu, and (**3**) Tambul. The locations of these sites are denoted by stars in Figure 1. The soil types were classified according the 1975 USDA scheme of soil taxonomy as: (**1**) Humult, (**2**), Aquept, and (**3**) Aqoll.

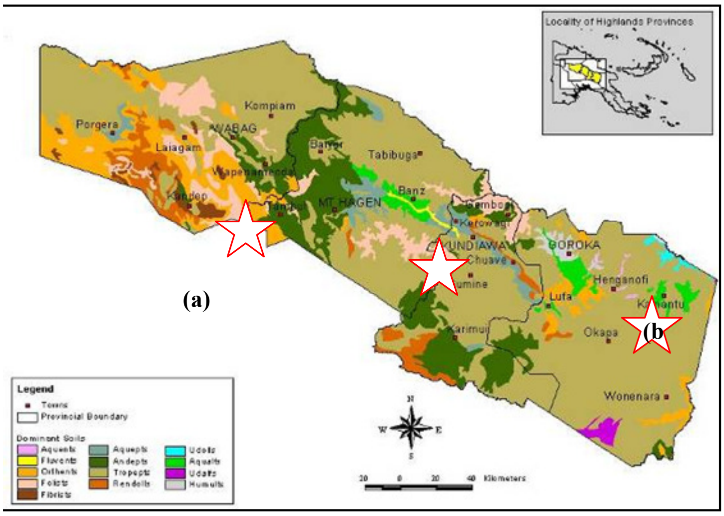

Figure 1. Map of four of PNG's highlands provinces showing dominant soil types according to the 1975 USDA soil taxonomy and locations of soils (stars) used in the nutrient omission trials.

Experimental protocol

Set weights of each soil were weighed into black polythene grow bags. The weight of soil plus bag and water needed to achieve 80% field water capacity was then determined. Nutrients (N, P, K, Ca, Mg, S, Fe, B, Mn, Cu, Zn, Mo and Ni) were added at rates given in Table 1 to give an ALL treatment plus 13 other treatments, each with one nutrient sequentially omitted. For example, the minus N treatment comprised all nutrients except for N, and the minus S treatment comprised all nutrients except for S. Sweetpotato vines, of similar weight and length were then planted, three per pot: Wahgi besta in Aiyura (**1**) and Kondiu (**2**) soils and Mae in Tambul (**3**) soil. Each treatment had 4 replicates, and these were laid out in a randomised block design in a screen house. After two weeks growth, the plants were thinned to two per pot, grown for a further four weeks and then harvested and total dry weight per pot determined. Leaf samples were collected at harvest from each pot for chemical analysis. Vine yield data were subjected to analysis of variance.

Table 1. Rates of nutrient application (kg/ha)

Nutrient	N	P	K	Ca	Mg	S	Fe	B	Zn	Mn	Cu	Mo	Ni
Rate (kg/ha)	190	112	160	68	56	48	10	4	8	8	6	0.8	0.2

Results and discussions

For the Aiyura soil, only the minus Mo treatment produced significantly less shoot yield than all nutrient control (Figure 2a). However, the concentration of Mo in shoots on the minus Mo treatment was considerably greater than the critical concentration (O'Sullivan *et al*. 1997). Clear symptoms of S deficiency, i.e. pale green/yellow coloration of leaves were present in plants grown on the minus S treatment (Figure 2b) even though vine yield on this treatment was not significantly less than that on the ALL control (Figure 2a). Leaf S concentration in the minus S treatment, however, was also appreciably less than the critical S concentration (Table 2) suggesting that S deficiency is potentially a problem in this soil.

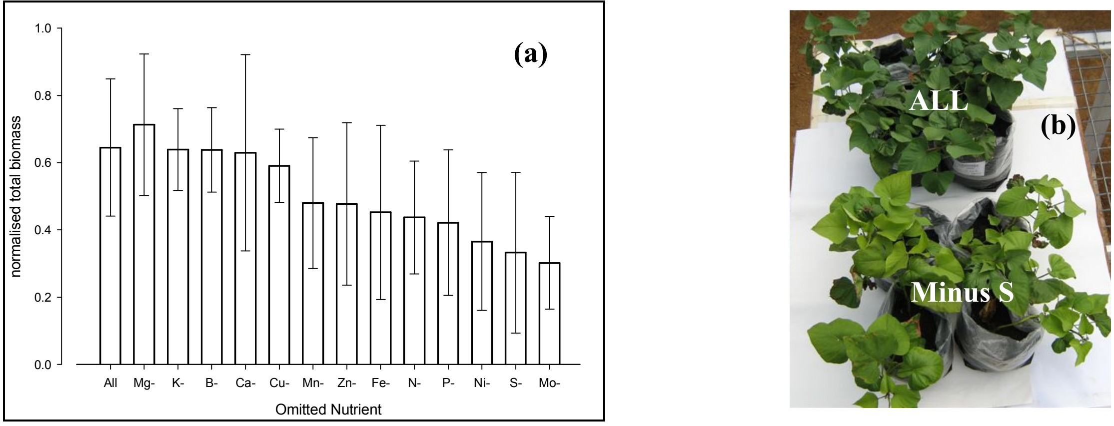

Figure 2 (a) Normalized DM yields of vines grown on soil from Aiyura and (b) photograph of S deficient vines on the minus S treatment against the All nutrient control just prior to harvest.

Table 2. Comparison of critical leaf nutrient concentrations (%) with leaf nutrient concentrations for the ALL, minus N, minus S and minus K treatments on each of the three sites/soil types.

Site/Soil	Aiyura/Humult			Kondiu/Aquept			Tambul/Aqoll		
	N	S	K	N	S	K	N	S	K
Critical nutrient concentration [a]	4.0	0.34	2.6	4.0	0.34	2.6	4.0	0.34	2.6
Concentration in ALL treatment	3.1	0.14	2.1	2.7	0.21	1.9	3.5	0.25	2.7
Concentration in Minus treatment	2.0	0.11	2.1	1.5	0.10	1.4	2.3	0.12	2.2

[a] (O'Sullivan *et al*. 1997)

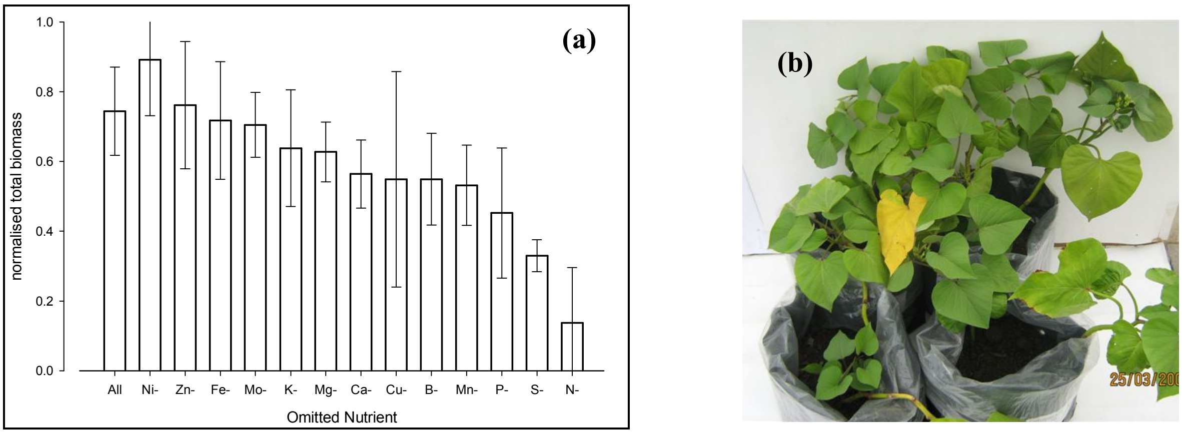

Figure 3 (a) Normalized DM yields of vines grown on soil from Kondiu and (b) photographs of vines on the minus S treatment showing pale green/yellow coloration typical of S deficiency.

Although the sweetpotato garden survey identified K deficiency as the major nutrient limitation on sweetpotato production, in this study, vine yield on the minus K treatment was not significantly different to that on the ALL treatment (Figure 2a). Likewise leaf K concentrations did not differ between the ALL and minus K treatments even though the concentration of K in soil was very low (0.02 meq/100g).

For the Simbu soil, the minus N, P, Ca, S, B and Mn treatments all had significantly less shoot yields than the control (Figure 3a), but the minus S and minus N treatments were lowest yielding, and the S deficiency was clearly manifest in the leaves, which were pale green/yellow in colour (Figure 3b). Leaf N and leaf S concentrations on the minus N and minus S treatments, respectively, were also appreciably less than the critical concentrations of these nutrients as determined by O'Sullivan *et al.* (1997). Vine yield on the minus K treatment was not significantly less than that on the ALL treatment even though the concentration on K in this soil was low (0.02 meq/100g). However, leaf K concentrations on both the ALL and minus K treatments differed little, although both were also appreciably lower than the critical K concentration.

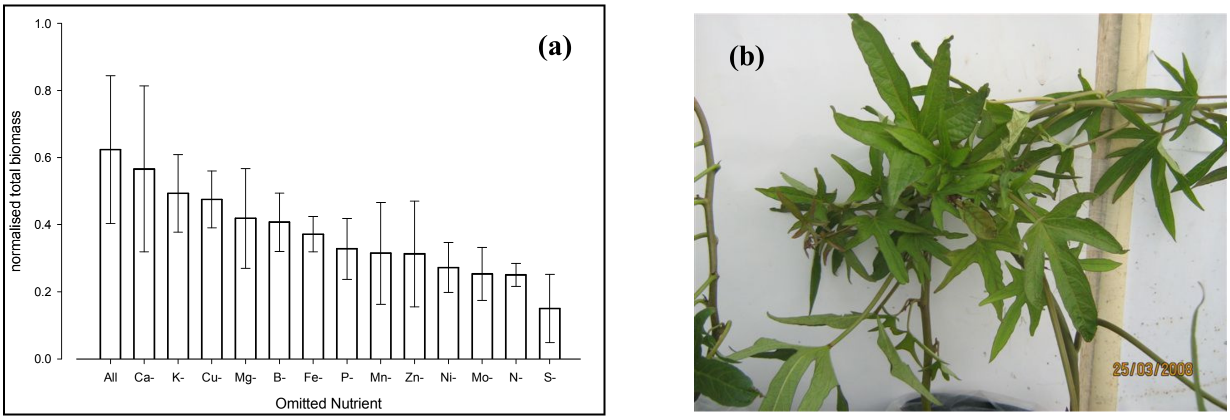

Figure 4 (a) Normalized DM yields of vines grown on soil from Tambul and (b) photographs of vines on the minus S treatment showing pale green/yellow coloration typical of S deficiency.

For the Tambul soil, the minus N, P, S, Mn, Zn, Mo and Ni treatments all had significantly lower vine yields than the ALL treatment (Figure 4a). Here again the minus S treatment produced the lowest yield, and the leaves were pale green/yellow in coloration (Figure 4b). Leaf S concentration was also appreciably lower than the critical concentration indicating that S deficiency is definitely a problem on this soil. The next lowest yielding treatments were the minus N and minus Mo treatments. However, while the concentration of

N in leaves on the minus N treatment was appreciably lower than either the critical N concentration or the N concentration in leaves on the ALL treatment (Table 2), the concentration of Mo in leaves on the minus Mo treatment was actually greater than the critical Mo concentration. Vine yield on the minus K treatment was not significantly less than that on the ALL treatment even though the concentration of K in soil was very low (0.02 meq/100g). Leaf K concentrations on both the ALL and minus K treatments differed little and were not appreciably lower than the critical K concentration (O'Sullivan *et al*. 1997).

Conclusions

For all three sites, S limitations appear to be affecting vine production potential, which is in keeping with the results from the sweetpotato garden survey. However, in contrast to the findings from this survey, which showed that K deficiency was the main nutritional limitation on sweetpotato production, K deficiency was not a problem for vine production on the three soils examined in this study, even though the levels of K in soil were very low. It should be noted though that the K requirement of sweetpotato is greatest during tuber formation and that this process does not commence until three months after vine planting, whereas in the present study vine cuttings were only propagated for 6 weeks. It is likely therefore that the K needs of the plants were adequately met from soil supplies plus existing K in vine tissue during this early stage of propagation. Based on the results, there seems to be scope for further trace nutrient studies on these soils focusing particularly on Mo, Ni and Mn limitations to sweetpotato production.

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Nutrient erosional losses in sub montaneous tract of northern India under simulated rainfall

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Abstract

Soil erosion is believed to be a major cause of nutrient depletion from soils, but there exists substantial variability and uncertainity among various estimates. We conducted simulated rainstorm studies on soils packed to field measured levels of bulk densities to determine nutrient removal with the eroded sediments for some soils of the sub-montaneous tract of northern India. Results demonstrated a positive correlation between the soils and the sediment concentrations of soil organic matter, and N, and a negative correlation for K, Ca, Mg, S, Cu and Mn. Enrichment ratios greater than unity for organic matter, N, K, Mg, Cu and Zn indicated preferential removal of these elements with the eroded sediments and the enrichment ratios lower than unity for P, S, Ca and Mn indicate preferential retention of these elements in the soil matrix under erosive rainstorms. This pattern will be significant for shaping the future fertility regimes of soils exposed to erosive rainstorms.

Key Words

Nutrient enrichment, soil erosion, rainfall simulator, soil fertility

Introduction

Nutrients lost through erosion have substantial on-site impacts affecting fertility and productivity of soil and off-site impacts through pollution of waterways. Soil erosion is one of the several processes contributing to onsite nutrient depletion. Nutrient depletion can also be a contributing cause of soil erosion because when nutrients are limiting, there is lower production of above and below ground biomass that protects the soil against erosion (Hashim *et al.* 1998). This is less frequently recognised than the fact that erosion causes nutrient depletion. In fact this makes up a cyclic relationship – erosion leading to nutrient depletion leading to increased susceptibility to erosion and further more erosion and so on. Most of the nutrient losses occur with the sediment fraction. The amount of nutrient loss per unit soil varies with soil type and is a function of the inherent nutrient status of the soil (Hargrave and Shaykewich 1997). Runoff enrichment studies quantify the effect of erosion on soil fertility and productivity. Enrichment ratios (ER) are calculated as the ratio of the nutrient content of sediment (eroded soil) to that of source soil. An ER >1 denotes that the sediment is richer in that nutrient than in the source soil, and an ER <1 denotes impoverishment of the sediment in that nutrient compared to the source soil. In the present study an evaluation has been made of the erosional losses of available nitrogen and ABDTPA extractable macro and micro-nutrients along with the eroded sediments from some soils of the submontaneous tract of northern India using laboratory scale simulated rainstorms under controlled conditions.

Methods

The soils selected for this study represent an area lying between 30° 40' to 32° 30' N latitude and 75° 30' to 76° 40' E longitude and comprising an ecologically fragile agro economic zone that poses serious environmental problems including land degradation. An assembly of soil boxes and a micro sprinkler based rainfall simulator was used for simulating rainfall and inducing erosion for the present study. The experimental soil boxes, 0.50 x 0.50 x 0.20 m^3, were fabricated from galvanized iron sheets in an arrangement for collecting infiltration. The base of the soil boxes was overlaid with a sieve sheet to enable separation of soil from the collected infiltration. The borders, on all sides of the soil boxes, were surrounded with a 20 cm wide horizontal sheet. The down slope end of the soil boxes was in the shape of a V-notch to enable the flow of runoff and sediments to the attached sediment collector which directed the flow of runoff and sediments through a funnel to the collecting vessels. The base of the soil boxes was also connected to a funnelled outlet to direct infiltrating water to the collecting vessels. Soil boxes were placed on iron stands of similar dimensions in length and breadth and a height of 0.5 m with a provision of adjusting the height of each side to level the soil boxes or to incline them to desired slopes. The empty soil boxes were placed on iron stands and levelled using the levelling screws. The sieved base was covered with a sheet of filter paper and overlaid with approximately 2 cm of a coarse gravel bed. The experimental soil sieved to pass through an 8 mm sieve was filled in the soil boxes above the gravel bed in 2 cm depth increments; hand levelled and compacted to the level of field measured bulk density. The top five cm of the soil in the boxes was harrowed with hand up and down the slope and left uncompacted to replicate the conditions of cultivated fallow prescribed for universal soil loss equation measurements. The depth of the soil overlying the gravel bed was approximately 12-cm. The soil boxes initially set flat and packed with soil, were wetted from the bottom and allowed to saturate overnight. The soil in the boxes was then allowed to drain freely for 24 hours and inclined to a slope of 9% by raising the upstream end of the soil boxes by 4.5 cm. Triplicate packed samples of each soil were prepared for simulated rainfall studies using a rainfall simulator (Kohli and Khera 2008). This assembly was operated continuously to collect about 60 L of runoff. The sediment in the runoff collected in the final run was allowed to settle for 24 h and separated from runoff water by decantation followed by filtration of the remaining puddle. The sediment collected was then air dried and stored for further laboratory analysis for organic C by the Walkley and Black method (Allison 1965), available nitrogen by alkaline $KMnO_4$ method (Subbiah and Asija 1956) and Ammonium Bicarbonate-Diethylene Triamine Penta Acetic Acid (ABDTPA) extractable P, K, Ca, Mg, S, Fe, Cu, Mn and Zn by plasma emission spectroscopy using ICAP (Jones 1977).

Results and Discussion

The organic matter content of the sediments (mean = 4.53 %, se = 0.23) was much higher than that of the original soil (mean = 0.57%; se = 0.08). The mean enrichment ratio of organic matter was 9.86 (se = 1.28). Organic matter enrichment was significantly correlated with soil organic matter content and soil organic matter content accounted for 90 per cent of the variation in organic matter enrichment when fitted as a logarithmic function. Available nitrogen in the soils ranged from 8 ppm to 34.67 ppm and in the eroded sediments from 18.67 ppm to 51.33 ppm. The average enrichment ratio for available nitrogen was 2.61 (se = 0.23). Teixeria and Misra (2005) have also reported from simulated rainfall erosion experiments that N concentration was greater in the sediments than in the un-eroded soil (signifying ER >1). Sediment enrichment of available N was significantly and negatively correlated (r = -0.73) with available soil N. Teixeria and Misra (2005) have also reported that the soil with highest fertility in terms of N concentration, was not only less susceptible to erosion but also to loss of fertility. Available soil N explained up to 67 per cent of the variation in the N enrichment ratio (ERN) of sediments when enrichment ratio was fitted as an exponential function of available soil N.

$$\mathrm{ERN} = 4.316\, e^{-0.0339 \times (\text{Available soil N})} \qquad (r^2 = 0.67) \qquad (1)$$

The concentration of ABDTPA extractable P in the soils and the eroded sediments ranged from 6.12 ppm to 55.00 ppm and 2.30 ppm to 19.25 ppm, respectively. The average enrichment ratio for ABDTPA extractable P was 0.46 (*se* = 0.07). However, no significant correlation was found between sediment enrichment of ABDTPA extractable P and the ABDTPA extractable soil P.

The concentration of ABDTPA extractable K in the soils and the sediments ranged from 25.18 ppm to 258.98 ppm and 27.44 ppm to 98.64 ppm respectively. The average enrichment ratio for ABDTPA extractable K was 1.21 (*se* = 0.18). Sediment enrichment of ABDTPA extractable K was significantly and negatively correlated (r = -0.65) with ABDTPA extractable soil K. ABDTPA extractable soil K accounted for 84 per cent of the variation in the K enrichment ratio (ERK) of sediments when enrichment ratio was fitted as an exponential function of ABDTPA extractable soil K.

$$\mathrm{ERK} = 2.09 e^{-0.0118\,(\text{ABDTPA extractable soil K})} \qquad (r^2 = 0.84) \qquad (2)$$

The role of soil structure and soil aggregates, which was not been investigated in this study, could also be a potential controlling factor for N losses in erosion. For soils with a more stable structure, the increased concentration of N-rich aggregates, in the sediment probably results from the presence of plant residues and an N-rich outer layer removed from larger aggregates by raindrop stripping (Ghadiri and Rose 1991a, b). Not withstanding these, Teixeria and Misra (2005) have asserted that for a wide range of soils and erosion conditions, loss of N by erosion could be reasonably estimated from the knowledge of soil loss alone. The micaceous minerals in the silt and clay fractions (Catt 2001) could have enriched the sediment in K. Most of the nutrient losses occur with the sediment fraction and the amount of nutrient loss per unit soil varies with soil and is a function of the inherent soil nutrient status (Hargave and Shaykewich 1997). The selective removal of N, P and K in runoff will reduce soil fertility and productivity. The transport of N, P and C is primarily associated with clay sized minerals and organic particles (Foster *et al.* 1980). Zhang and Shao (2001) have shown that enrichment of clay results in the enrichment of organic matter and total nitrogen.

Sediment bound nutrients may account for up to 90 per cent of the total amount transported in runoff (Schuman *et al.* 1973 a & b). Alberts *et al.* (1983) reported that much of total N was transported by the larger aggregates (> 50µm) which would be expected because organic N is primarily associated with the clay fraction of the soil (Frere 1976). They also suggested that smaller aggregates have a higher capacity to buffer soluble P levels because of a larger number of accessible sorption sites. So at a common equilibrium phosphorus concentration, smaller aggregates will transport greater quantities of labile P per gram. Although P transport in runoff is associated with clay-sized particles, the preferential transport of Brays I P or Labile P increased during erosion compared to the source soil. This increase may result from a selective erosion of certain clay minerals and fine clays having an increased Brays I P and Labile P content and / or a decrease in particle aggregation compared to the surface soil.

ABDTPA extractable calcium in the soils ranged from 227 ppm to 344 ppm and in the eroded sediments from 223 ppm to 301 ppm. The average enrichment ratio for ABDTPA extractable calcium (ERCa) was 0.937 (*se* = 0.05). Sediment enrichment of ABDTPA extractable calcium was significantly and negatively correlated (r = -0.89) with ABDTPA extractable soil calcium. ABDTPA extractable magnesium in the soils ranged from 6.9 ppm to 112.6 ppm and in the eroded sediments from 129.0 ppm to 235.3 ppm. The average enrichment ratio for ABDTPA extractable magnesium (ERMg) was 5.82 (*se* = 1.48). Sediment enrichment of ABDTPA extractable magnesium was significantly and negatively correlated (r = -0.82) with ABDTPA extractable soil magnesium. The concentration of ABDTPA extractable S in the soils and the sediments ranged from 11.2 ppm to 39.3 ppm and 4.9 ppm to 10.2 ppm respectively. The average enrichment ratio for ABDTPA extractable S (ERS) was 0.36 (*se* = 0.04). Sediment enrichment of ABDTPA extractable S was significantly and negatively correlated (r = -0.80) with ABDTPA extractable soil S. The ABDTPA extractable contents of Ca, Mg and S in the soil matrix accounted for 83, 90 and 68 per cent of the variation in their respective enrichment ratios when fitted as exponential functions.

$$ERCa = 3.6444e^{-0.005\ (\text{Available soil Ca})} \qquad (r^2 = 0.83) \qquad (3)$$

$$ERMg = 14.727e^{-0.0241\ (\text{Available soil Mg})} \qquad (r^2 = 0.90) \qquad (4)$$

$$ERS = 0.7309e^{-0.0327\ (\text{Available soil S})} \qquad (r^2 = 0.68) \qquad (5)$$

The enrichment ratios less than unity for calcium and sulfur indicate that there is actually an impoverishment of calcium and sulfur in the eroded sediments in comparison to the matrix soil. This leads us to believe that there will be an actual enrichment of the matrix soil in Ca and S and an impoverishment in Mg with continued erosion over a period of time.

ABDTPA extractable Fe in the soils ranged from 5.3 ppm to 100.4 ppm and in the eroded sediments from 3.8 ppm to 61.0 ppm. The average enrichment ratio for ABDTPA extractable Fe (ERFe) was 0.98 (*se* = 0.20). This little enrichment of iron in the eroded sediments in comparison to the matrix soil did not show any significant correlation with the available Fe content of the matrix soil. ABDTPA extractable Cu in the soils ranged from 0.3 ppm to 2.8 ppm and in the eroded sediments from 0.8 ppm to 4.3 ppm. The average enrichment ratio for ABDTPA extractable Cu (ERCu) was 2.32 (*se* = 0.34). Sediment enrichment of ABDTPA extractable Cu was significantly and negatively correlated (r = -0.66) with ABDTPA extractable soil copper. The concentration of ABDTPA extractable Mn in the soils and the sediments ranged from 20.5 ppm to 97.0 ppm and 2.9 ppm to 19.7 ppm respectively. The average enrichment ratio for ABDTPA extractable Mn (ERMn) was 0.30 (*se* = 0.06). Sediment enrichment of available Mn was significantly and negatively correlated (r = -0.56) with available soil Mn. The low enrichment ratio for Mn indicates that there is actually an impoverishment of Mn in the eroded sediments in comparison to the matrix soil with erosion over time. The concentration of ABDTPA extractable Zn in the soils and the sediments ranged from 1.5 ppm to 3.2 ppm and 12.6 ppm to 63.6 ppm respectively. The average enrichment ratio for available Zn (ERZn) was 14.51 (*se* = 2.00) which indicates high preferential removal of Zn along with the eroded sediments. However, the sediment enrichment of Zinc did not show any significant correlation with ABDTPA extractable Zn concentration in the soil. These results suggest that continued erosion over time could lead to a soil matrix that is almost similar in available Fe, relatively enriched in Mn and impoverished in Cu and Zn as compared to the original soil matrix. The ABDTPA extractable contents of Cu and Mn in the soil accounted for 63 and 35 per cent of the variation in their enrichment in the eroded sediments when fitted as logarithmic functions.

$$ERCu = -1.3017\text{Ln}(\text{Available soil Cu}) + 2.1731 \ (r^2 = 0.63) \qquad (6)$$

$$ERMn = -0.2281\text{Ln}(\text{Available soil Mn}) + 1.1482 \ (r^2 = 0.35) \qquad (7)$$

Conclusions

Significant positive correlation was found for organic matter and available N soil contents with their enrichment in eroded sediments as compared to the parent soil. However, a significant negative correlation was found for the respective contents of ABDTPA extractable K, Ca, Mg, S, Cu, and Cu and Mn in the soil, with their enrichment in the eroded sediments as compared to the parent soil. Phosphorus, Fe and Zn concentration in the soil did not show any significant correlation with the enrichment ratios of the erodent sediments as compared to the original soil matrix. The enrichment ratios greater than unity for OM, N, K, Mg, Cu and Zn, and lower than unity for P, Ca, S and Mn signify the preferential removal in the eroded sediments and retention by the soil matrix, respectively. This has significance in shaping future fertility regimes for soils exposed to erosive rainstorms.

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Pattern and behaviour of gully erosion in Shiwaliks of lower Himalayas

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Abstract

A study on behaviour and pattern of gully erosion in foothills of Shiwaliks of lower Himalayas was conducted in 68 micro-catchments. The average gully density was 19.8 km/km^2 and the average gully texture was 839 /km^2 observed in the region. The average length of 1st order gullies, which are primary points of runoff water collection, was 60.7 %, whereas the average number of 1st order gullies was 74.3 %. A bifurcation ratio of 3.4 was observed between first and second order gullies for whole of the region. Temporal study of gully development suggests relatively higher increase in gully depth as compared to their length or width.

Key Words

Soil erosion, gully length, gully number, gully distribution

Introduction

The foothills of Shiwaliks covering an area of 2.14 m ha falls in four states of India i.e. Punjab (0.14 m ha), Haryana (0.06 m ha), Himachal Pradesh (1.14 m ha) and Jammu and Kashmir (0.80 m ha) and represents the most fragile ecosystem of Himalayan mountain range because of its peculiar geological formations and highly erodible soils (Singh and Khera 2009). Runoff and soil loss in the region varies from 35- 45% and 25-225 t/ha/year, respectively (Sur and Ghuman 1994). Among different types of soil erosion, gully erosion is the most serious one in the region as around 20% of the area is already under gullies (Kukal and Sur 1992). Ephemeral gully erosion has been reported to account for 48.5 to 72.8% of the total soil loss (Zheng *et al.* 2009). About 70-80% of the gully erosion control structures have failed in the region (Kukal *et al.* 2002). The reasons attributed for the failure of gully control structures in the region include lack of information on gully network including distribution and extent of different-ordered gullies, gully density, gully texture, behaviour and development of gullies in the region. Secondly, the installation of gully control structures is generally done in the highest-ordered gully on lower, middle and upper segments of the catchment. After some time, the gully control structure gets silted up along the upstream side, after which the runoff water starts falling down from the crest height of the structure and causes higher erosion losses. The lower ordered gullies are seldom tackled in the region while controlling the runoff and soil loss and are generally ignored in all the soil conservation programmes. The present study aims to have an insight into the behaviour and patterns of gully erosion in the foothills of lower Shiwaliks and to study the nature of gully development and distribution patterns in the region.

Methods

Study area

The study was carried out in 68 catchments in the Shiwaliks region of Lower Himalayas in North India. The region lies between 30^0 10' to 33^0 37' N latitude and 73^0 37' to 77^0 39' E longitude and stretches to about 530 km lengthwise and 25 – 95 km width wise.

Gully erosion survey

A detailed field survey for gully erosion was carried out by dividing catchments into grids of 50 × 50 m^2 each. For the detailed field survey, each gully line was sketched on the contour maps (at a scale of 1: 1000) manually after measuring the distance between wooden pegs laid out in the grids. The gullies up to the first-order were marked on the maps. Gullies were classified as 1st, 2nd, 3rd, 4th and 5th order gullies, depending upon extent of their bifurcation. The length of different ordered gullies was measured in each catchment from the gully erosion map. The total length of all the gullies in the catchment were expressed as “gully density” (km/km^2). The number of first-order gullies per unit area was expressed as “gully texture” (number/km^2).

Gully development process

Detailed gully development process was studied in four selected catchments in the region by selecting the strategic sites prone to gully erosion and monitoring the initiation process and gradual advancement of

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

gullies at different time intervals. The temporal variations in gully dimensions on both non-arable and arable land were observed after 21, 41 and 77 days with respect to the first day observation. The width, length and depth of the gullies were measured and from this total volume of the gully calculated.

Results

Extent of Gully Erosion

The extent of gully erosion expressed on the basis of gully density and gully texture is presented in Table 1. The average gully density was 19.85 km/km^2 and the average gully texture in the region was 839 number/km^2. The catchments of location I observed the highest value of gully density (30.52 km/km^2) and gully texture (1921.5/km^2) among all the sites.

Distribution of different-ordered gullies

The average length of 1st, 2nd and 3rd gullies was 60.7, 22.8 and 10.3% per cent, respectively with standard deviation of 8.66, 7.03 and 6.51 (Table 2). The average number of 1st, 2nd and 3rd order gullies was 74.3, 22.1 and 3.12%, respectively with standard deviation of 6.21, 4.99 and 2.06, respectively (Table 2). Unlike the length of first-ordered gullies (the main runoff collecting channels), the number of first-order gullies did not differ much among various catchments (72-77%). The first-ordered gullies collect runoff from the remotest points of the catchment and supply the same to the 2nd order gullies. The runoff is then conveyed further to 3rd, 4th and 5th ordered gullies and ultimately the highest order gully carries it out of the catchment.

There was a definite bifurcation ratio observed between first and second order gullies. A bifurcation ratio of 3.4 was observed for whole of the region. It could be used to predict the number of first order gullies from the number of second order gullies. A definite relation was observed between the gully order and mean length of gullies. The mean length of gullies increased with increase in gully order. The number of different ordered gullies draining into the higher order gullies shows that about 54, 29 and 17% of the 1st order gullies drained into the 2nd, 3rd and 4th order gullies, respectively whereas 64 and 36% of 2nd order gullies drained directly into 3rd and 4th order gullies, respectively.

Temporal variations

The gullies in the region have been observed to grow in all the three directions both on arable and non-arable lands with time leading to addition of the sediments in the running water. The width of the gullies in non-arable lands increased by 3.72 to 9.6% within a period of 77 days, whereas the length and depth of the gullies increased by 3.1 to 8.9% and 8.3 to 26.7%, respectively. The increase in gully depth was more conspicuous than gully width and length. It could be due to the reason that the subsoils in the region are more erodible than surface soils and once the surface soil gets eroded, the gully depth increases at a faster rate. This is true in case of gullies on arable land which are deeper than the gullies on the non-arable lands.

Table 1. Extent of gully erosion in the study catchments.

Location	Number of catchments	Gully density (km/km^2)			Gully Texture (number/km^2)		
		Range	Mean	SD	Range	Mean	SD
I	4	8.6 - 31.7	17.9	9.78	251.2 - 758.0	542.7	240.86
II	4	3.5 - 80.0	30.5	33.93	425.0 - 4966	1921.5	2058.06
III	16	3.2 - 45.1	15.6	13.45	157.1 - 1575	647.2	437.86
IV	20	2.8 - 62.8	20.3	16.01	93.6 - 2314.0	620.8	518.06
V	24	3.2 - 28.0	14.9	6.05	258.0 - 912.5	462.1	177.26

Table 2. Distribution of length of different ordered gullies in the study catchments.

Location	Gully Length (%)			Gully Number (%)		
	1st order	2nd order	3rd order	1st order	2nd order	3rd order
I	71.85	27.45	1.17	77.43	21.98	0.83
II	75.25	20.25	4.00	74.90	22.38	2.73
III	55.70	24.11	10.78	72.39	21.77	4.58
IV	52.47	19.76	18.76	73.24	21.71	4.15
V	47.80	22.48	16.75	73.37	22.50	3.30

Conclusion

The gully density ranged from 2.8 to 80 km/km^2 with a mean value of 19.8 km/km^2 and gully texture varied from 93.6 to 4966 /km^2 with a mean value of 840 /km^2 in the region. First order gullies dominated in the region and mean length of gullies increased with increase in gully order. Depth of gullies is comparatively higher both under arable and non-arable land uses.

Acknowledgement

The study was conducted with the financial support from Department of Science and Technology, Government of India.

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Phosphorus behaviour in sediments from a small agricultural watershed under oxic and anoxic conditions

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Abstract

The use of soil outside of its capacity generates great amount of sediments and can transfer phosphate to water courses, giving rise to eutrophication. The present work aims to estimate the phosphorus desorption capacity of sediments transferred in the small watershed of Arroio Lino brook, in Agudo town, Brazil, under oxic and anoxic conditions. Samples of water + sediments were collected at four points (two subwatersheds, upstream and downstream) in two pluviometric events (winter fallow and tobacco seedling transplanting). The concentration of sediments in suspension in the water courses is related to the rainfall characteristics and soil use. The amounts of bioavailable particulate phosphorus and potentially bioavailable particulate phosphorus desorbed from sediments are increased by anthropic activity. Under anoxic conditions, the bioavailability of phosphorus in the sediments increased, increasing its effect on the eutrophication of lentic water environments.

Key Words

River sediments, phosphorus desorption, particulate phosphorus, tobacco production.

Introduction

In the tobacco production systems performed under conventional tillage, inorganic fertilizer is usually added in excess. In the conventional tillage management, the potential for soil erosion increased by topsoil ploughing in preparation for seeding and erosion can be accelerated during run-off events. Substances dissolved and suspended in runoff, such as nitrogen and phosphorus, are transported from the soil to the water courses along three pathways: overland flow (surface run-off), leachate (sub-surface run-off) or sub-surface groundwater flow (Reynolds and Davies 2001). Surface run-off occurs during and immediately after an intense precipitation and promotes the transfer of dissolved, colloidal or fine-particulate phosphorus from the topsoil to the water streams, eventually leading to eutrophic conditions and decreasing biodiversity of the surrounding surface water. The transport of phosphorus-containing particulates is greater from cultivated ground than from grassland; the phosphorus losses from agricultural areas are mostly as particulate-P, that is, the sediments act as phosphorus carriers (Pietiläinen 1997). The amount and quality of P losses depend on the magnitude of point-source P discharges and the dominance of P pathways. Natural buffer zones (such as riparian zones) can act as a P trap along the agricultural fields. The impact of particulate-P input on the eutrophication of surface waters depends on the sediment-water interactions and the processes behind retention and release of P. Some fractions of phosphorus in sediments are virtually permanently bound in the solid particle, while others are potentially mobile, and under appropriate conditions can lead to P release to the solution. P in solution is the only one available for biological uptake. The size and composition of the particles and the redox conditions of the environment play a major role on the P release. In soils the importance of Fe- and Al-rich amorphous minerals as carrier phases of P is well known (Beauchemin *et al.* 1999). Clays are important P-carrier phases of the colloidal fractions on river sediments. Part of the clay-bound fraction of particulate-P may be in the form of iron oxides or organic coatings (Poulenard *et al.* 2008). Iron and aluminium oxides play a significant role in the phosphate buffer mechanism of fluvial sediments, as they can act as a sink for phosphorus, maintaining low equilibrium phosphate solution concentrations (Froelich 1988). However, under anaerobic conditions, reductive dissolution of ferric hydroxides carrying P is an important orthophosphate release mechanism, increasing P bioavailability (Shenker *et al.* 2005).
In this study the sediments are submitted to phosphorus desorption under oxic and anoxic environments in the laboratory.

Methods

Site description

The Lino stream watershed (480 ha) is located in the Nova Boêmia community, town of Agudo, Rio Grande do Sul state, Brazil, at coordinates Universal Transvere Mercator (UTM) 22 J 280000–283500 m/6733500–

6737000 m. This typical agricultural watershed is an important tributary of the Jacuí River. As concerning the geological aspects, the watershed belongs to the "Serra Geral Formation," which presents basaltic hillsides and localized outcrops of Botucatu sandstone. The land altitude ranges from 100 to 500 m with long pendants and short slopes normally greater than 25°. The soils are classified as Mollisols and Inceptisols (Soil Survey Staff 1999) and the vegetation is composed by remnant seasonally deciduous forests in different stages of succession. The climate is humid subtropical, with an average annual rainfall of 1,600 mm and an average annual temperature of 19°C. Almost 25% of the watershed's area is occupied by annual crops and more than 60% by native forest cover. Approximately 90% of the 36 farm production units are devoted to tobacco production. Tobacco is an intensively tilled crop, and its production system typically includes two to six cultivation operations per year (disk plow and disk harrowing 0.20 m soil disturbance depth). In addition to intensive tillage for weed control and preparation for tobacco transplanting, tobacco production employs many pesticides (insecticides, fungicides, and herbicides) to enhance leaf growth.

Sediment sampling

Water and suspended sediments were collected at the exit of four points (subwatersheds A and B; upstream and downstream). Subwatershed A (right stream) with a landscape conformation based on high sloped relief and high human activity. Agricultural fields are close to streams and with no protection by vegetation in stream-adjacent areas. Subwatershed B (left stream) with a landscape conformation based on highly sloping relief and high human activities. However, this subwatershed presented high soil cover by natural vegetation around stream areas; therefore, the agricultural fields are located far from streams in both collected points. Water and sediment samples were taken immediately after each of two rainfall events: fallow winter (average precipitation = 55 mm and maxima precipitation = 47 mm/h) and tobacco transplanting – seedling (average precipitation = 38 mm and maxima precipitation = 17 mm/h). The employed samplers are an adaptation of the model US U-59 (CEWEH-Y 1995), installed in pairs in the streambed of the watercourse. The suspended sediments of the two automatic samplers were mixed in a single sample.

Physico-chemical analysis

In laboratory, initial pH values were determined in water and sediment suspension samples. The soluble P was determined in water filtered a 0.45-µm porous membrane (Murphy and Riley 1962). The soluble carbon was determinate by wet combustion and colorimetric analysis. After evaporation at 100°C, the sediment concentration was quantified. Iron was extracted by dithionite–citrate–sodium bicarbonate (Fed) and by oxalate (Loeppert and Inskeep 1996) and total organic carbon by dry combustion (Flash EA1112). P of sediment was extracted by acid digestion ($H_2O_2 + H_2SO_4 + MgCl_2$ at 200°C), and this value was assumed as total P (Rheinheimer *et al.* 2003).

Phosphorus desorption

Phosphorus desorption capacity was estimated by successive extractions with an Anionic Exchange Resin (AER) membrane (Rheinheimer *et al.* 2003) in a water-jacketed glass reactor vessel. A constant suspension temperature of 25^{o}C was achieved using a circulating water bath system. The desired Eh in the reactor suspensions were obtained by purging with N_2 to induce reducing conditions (+20±50 mV) or opening the vessel to air to achieve oxic environment (+420±50 mV). A first-order kinetic model (McKean and Warren 1996) was employed to fit the desorption curves, allowing the estimate of the potentially bioavailable particulate P (β), and the bioavailable particulate P, which is the P desorbed in the first extraction (α).

Results

Sediment concentration and physical and chemical properties of sediments

In both rain events, the non-anthropized subwatershed released a much lower concentration of sediments than the others subwatersheds (Table 1), which highlight the important role of riparian zones in avoiding erosion by interception of drainage (Lowrence 1998). Sediments deriving from the non-anthropized watershed presented lower values of pH, soluble P, total P and Fe and higher contents of total organic carbon. In sediments of the anthropized subwatersheds, the amount of iron extracted by DCB was, approximately, 4 and 2 times those deriving from non-anthropized areas, for the two pluviometric events. This is a consequence of the low soil cover index, which facilitates soil disaggregation and, consequently, the dragging of sediments with the torrent of rain water. In the low precipitation event (tobacco seedlings transplanting) the sediment concentrations and the iron amounts extracted by DCB were lower than those corresponding to the winter fallow rainfall event. However, the forms of iron extracted by oxalate have not changed significantly, giving rise to the diminishing Fed/Feo ratio.

Table 1. Sediment concentration, soluble and total phosphorus, iron extracted by dithionite–citrate–sodium bicarbonate (Fe_{DCB}) and by oxalate (Fe_O), and ration Fe_{DCB} / Fe_O, soluble and total organic carbon from sediment collected at four points in the two agricultural sub-watersheds during two rain events.

Subwatershed	Sediment concentration (g/l)	Soluble phosphorus (mg/l)	Total phosphorus (TP) (mg/kg)	Iron DCB (Fe_{DCB}) (g/kg)	Iron oxalate (Fe_O) (g/kg)	Ratio Fe_{DCB} / Fe_O	Soluble carbon (mg/l)	Total carbon (g/kg)
				Winter fallow				
Right stream								
Upstream (non-anthropized)	0.1	0.04	659.5	19.5	0.8	24.4	4.72	74.7
Downstream	12.8	0.02	916.4	71.5	4.2	17.0	2.87	18.3
Left stream								
Upstream	4.9	0.20	1011.0	74.9	2.7	27.7	3.49	24.1
Downstream	5.7	0.08	1037.0	86.0	2.4	35.8	1.95	15.9
				Tobacco seedlings transplanting				
Right stream								
Upstream (non-anthropized)	0.1	0.01	621.5	12.3	0.6	20.5	4.62	103.2
Downstream	2.3	0.25	963.5	23.1	4.1	5.6	6.87	21.7
Left stream								
Upstream	1.1	0.18	996.4	22.6	5.7	4.0	6.00	55.0
Downstream	0.9	0.22	1165.0	20.1	5.3	3.8	5.59	26.7

Table 2. Phosphorus desorption from sediments collected in two rain events, winter fallow and seedlings transplanting, at different subwatersheds, submitted to oxic and anoxic conditions.

Subwatershed	Bioavailable particulate phosphorus (mg/kg)		Potentially bioavailable particulate phosphorus (mg/kg)	
	Oxic	Anoxic	Oxic	Anoxic
			Winter fallow	
Ride stream				
Upstream (non-anthropized)	0.9	28.7	38.9	58.4
Downstream	11.1	22.7	52.5	59.2
Left stream				
Upstream	22.9	36.0	109.6	121.3
Downstream	28.3	44.7	113.0	128.7
Ride stream		Tobacco seedlings transplanting		
Upstream (non-anthropized)	0.3	31.6	19.9	80.8
Downstream	59.4	69.6	238.3	244.7
Left stream				
Upstream	67.0	94.5	306.7	345.8
Downstream	83.0	84.1	234.3	243.8

Phosphorus desorption

In oxic condition, the bioavailable particulate P (α) and the potentially bioavailable particulate P (β) from sediments collected at the non-anthropized subwatershed were very low (< 1 mg/kg and < 40 mg/kg, respectively). Sediments collected during tobacco seedling transplanting, in the anthropized subwatersheds, showed higher bioavailable particulate P than those of the winter fallow rain. For example, in the seedlings transplanting event, the β value was 306.7 mg/kg in the upstream point of the left stream, but it changed to 109.6 mg/kg in the winter fallow rainfall (Table 2). This result is not explained by the sediment concentration, since lower losses of sediments were observed for the seedlings transplanting rainfall, as a consequence of the lower total and average precipitation intensity. Probably, this difference can be attributed to the phosphate originating from the soluble phosphate fertilizers added before tobacco seedlings transplanting.

When the sediments were submitted to anoxic conditions, there was an increase in P desorption, especially in non-anthropized watershed (Table 2) because there are the highest amount of carbon organic total (Table 1). In oxic environments, the microorganisms promote the oxidation of organic carbon and the electrons generated by the oxidation are accepted by oxygen dissolved in the water, therefore being reduced to water. Under lower redox potential*,* in absence of dissolved O_2, the oxidation of organic carbon occurs only if another electron acceptor is present. For sediments and soil particles, a possible electron acceptor is the Fe III present in the iron oxides structure, which is reduced to Fe II and dissolves in the water phase, along with its iron oxide-bound phosphate, increasing P bioavailability (Shenker *et al.* 2005).

Conclusion

The biggest amounts of bioavailable particulate phosphorus were obtained in sediments collected in the anthropized area during tobacco seedlings transplanting. Phosphorus desorption was higher when sediments were submitted to anoxic conditions, especially for those derived from non-anthropized areas, have larger total organic carbon contents.

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Phosphorus persistence in runoff from an Ultisol amended with dairy manure sludge

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Abstract

Five consecutive simulated rainfall events were performed over a 45-day period on an undisturbed soil (Typic Haplohumult) under forage (*Brachiaria decumbens*) production. The soils had Bray-1 soil test phosphorus (STP) in the "high" (range of 30 to 90 mg P/kg) and "very high" (range of 91 to 200 mg P/kg) categories and were amended with a low (15.5 kg N/ha and 5.6 kg P/ha) and a high (31 kg N/ha and 11.2 kg P/ha) application of fresh dairy manure sludge. The concentrations of dissolved P (DP), total P (TP) and suspended sediment (SS) concentrations in runoff were quantified. Runoff DP and TP concentrations were primarily influenced by the "very high" STP level and to a minor extent by the high manure application. Nutrient concentrations were higher on the first day after manure application and were highest in soils with "very high" STP levels. The concentrations of DP and TP in runoff 4, 8, 15 and 45 days after manure application decreased on average by 52, 40, 36, and 35%, respectively, relative to the first day. Manure management for agricultural soils should be guided by soil test P levels, manure dose applications and expected rainfall events.

Keywords

soil test phosphorus, nutrient in runoff, dairy manure sludge, water quality, tropical soils.

Introduction

Long-term application of dairy manure sludge based on crop N requirements leads to soil P accumulation in soils of the tropics (Torres *et al.* 2009). The runoff phosphorus (P) concentrations have been quantitatively related to agronomic soil tests for P such as: Olsen extractant, Bray-1, or Mehlich-3 (Sims and Wolf 1995). Increasing STP leads to higher runoff P concentrations as observed using linear, non-linear and split-line relationships (Sharpley 1995; Daverede *et al.* 2003; Kleinman *et al.* 2004). Although Ultisols having the oxidic and kaolinitic mineralogy of the tropics may have enhanced capacity to reduce soil solution P due to precipitation and adsorption reactions, it seems that there are similar trends in the relationships between STP and P concentrations in runoff between Ultisols and other soils of temperate areas.

Ramírez-Ávila *et al.* (2008) reported that the quantitative relations between STP and runoff P concentrations vary due to soil organic matter, ground cover, soil moisture and amendment applications. It is not clear what are the mechanisms explaining why there is less P in runoff in wet soils than in dry soils or in the second of two consecutive runoff events. Runoff P concentrations are highest immediately after P application and decrease with time (Edwards and Daniel 1993). Although sorption and precipitation processes have been documented to control soil solution P, other mechanisms such as leaching, increased dilution of transported P, losses of the most labile P fraction and increased soil P extractability in dry soils may contribute (Pote *et al.* 1999; Kleinman and Sharpley 2003). Evaluation of mechanisms controlling runoff P at the field scale is affected by weather fluctuations, landscape heterogeneity, spatial variability and animals. Indoor rainfall simulations using boxes are an alternative to evaluate patterns of runoff nutrient concentrations (Sharpley and Kleinman 2003; Guidry *et al.* 2006). We carried out rainfall simulations using intact soil cores to evaluate runoff nutrient concentrations as influenced by STP, manure application and time after manure application.

Methods

Two grazed pasture production fields, with and without dairy manure sludge application, from a commercial dairy production farm in Puerto Rico were selected. Within each field, areas having "high" and "very high" STP categorical levels (Sotomayor-Ramirez *et al.* 2004) were identified. Intact rectangular soil (Typic Haplohumults) cores (100 x 30 x 9 cm) were collected from each area, trimmed and placed in galvanized sheet metal runoff boxes with similar dimensions (100 x 20 x 7.5 cm). Soil samples taken from each collection area at a depth of 0 - 10 cm, air dried, sieved to pass a 2-mm mesh, and analyzed for STP using

Bray-1 (Bray and Kurtz 1945). The runoff boxes were transferred to greenhouse facilities.

The experimental design was a 2 (high and very high STP categorical levels) × 3 (none, low and high dairy manure sludge levels) factorial with 5 replicates. The low and high manure dose achieved rates of 15.5 kg N/ha and 5.6 kg P/ha and 31 kg N/ha and 11.2 kg P/ha, respectively. Consecutive sequential (t) rainfall simulations were done for all treatments at 1, 4, 8, 15 and 45 days after manure application. A set of samples was left without rainfall simulations for 30 days and rainfall simulations were then performed at 30, 32, 38, 45 and 74 days after manure application.

Simulated rainfall with an intensity of 70 mm/hr was applied to each set of plots with a duration corresponding to 30-min of runoff (USDA-NRCS 2001). A 500 ml subsample was obtained from the cumulative volume of runoff collected. Samples were analyzed for total P (TP) after digestion, and dissolved P (DP) after filtration (Pote and Daniel 2009; Pote *et al.* 2009). The degree of P saturation (DPS) was quantified as described by Schoumans (2009). An ANOVA was performed on nutrient concentrations in runoff using PROC GLM of SAS (SAS Institute, Carey NC) using STP, and manure levels as fixed effects and time as repeated measures; mean separation was estimated by Tukey's test ($P<0.05$).

Results and Discussion

The mean soil organic matter was 88.0 g/kg (coefficient of variation, CV = 19%). The soil had a mean pH of 4.54 (CV = 6.69%), and had parasesquic mineralogy; conditions which promote P fixation. Exchangeable cations (Ca, Mg, K, Na) and soil electrical conductivity tended to be higher in soils with a dairy manure sludge application history. In general, as soil moisture decreases there occurs lower runoff volumes, higher time to runoff initiation, and lower runoff/ratio. In our experiment, we observed these trends only in the "very high" STP and high manure treatment. These same treatments also had higher DP and TP concentrations, throughout the consecutive rainfall events.

Runoff DP and TP concentrations, averaged across the five rainfall simulations over a 45-d period, were significantly greater ($P<0.01$) in soils with "very high" than "high" STP level, regardless of whether the soil was amended or not with manure (Figure 1). In general, runoff DP concentrations were 30, 37 and 48% higher in soils with "very high" STP than soils with "high" STP in unamended, low, and high manure application levels, respectively. The high manure application treatment increased DP and TP concentrations relative to low manure application treatment and unamended soil. Suspended sediment concentrations in runoff tended to be greater in soils with manure application than without manure application, although these were not statistically different ($P<0.05$).The DP/TP ratio in soils with "very high" STP was 90% and 81% in soils with "high" STP level. The proportion of P in runoff as particulate material was nearly 50% lower in soils with "very high" STP than in soils with "high" STP. The data suggests that at the field scale, as STP increases a greater proportion of the total P in runoff will be in dissolved form, but there will also be more P in particulate form.

In the first rainfall simulation after manure application (day 1), runoff DP and TP concentrations in soils with "very high" STP were significantly greater than for soils with "high" STP for both unamended and amended soils except for the treatment with high STP levels and high manure application (Figure 2). The DP and TP concentrations were reduced by 36 and 35%, respectively, on all other days (4, 8, 15 and 45) relative to day 1. The data clearly indicate that the most important determinant on DP and TP concentrations in the first rainfall event of a soil can be both the "very high" STP condition as well as a high manure amendment level. Runoff DP and TP concentrations were always lowest for soils with "high" STP without manure application and with low manure application level.

The major P losses in runoff will occur on the first day after dairy manure applications and after the first simulation, the DP concentrations in runoff were similar to rainfall simulations at 4, 8, 15 and 45 days (Figure 3). The relationship between DP and time can be modeled for the "very high" STP level [1] and for the "high" STP level [2], averaged across manure application, as:

$$DP = 0.6765\ (\text{day})^{-0.289};\ r^2 = 0.93 \qquad [1]$$
$$DP = 1.2346\ (\text{day})^{-0.14};\ r^2 = 0.95 \qquad [2]$$

A set of soils did not receive rainfall simulations for a 30-day period, after which simulations were performed at days 32, 38, 45 and 74 days. Runoff concentrations of DP and TP were similar for days 32, 38, 45 and 74 of simulation (data not shown). Runoff DP concentrations in soils with "very high" STP after 45 days of consecutive rainfall simulations (five events) were similar to those which had not received simulated rainfall simulations.

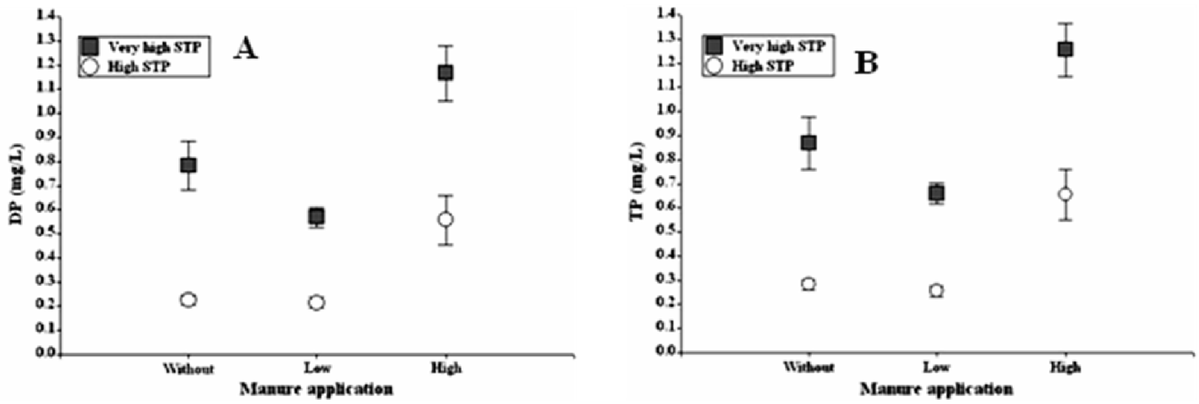

Figure 1. Effect of manure application level and soil test phosphorus (STP) on (A) dissolved P and and (B) total P concentrations in runoff from Ultisols.

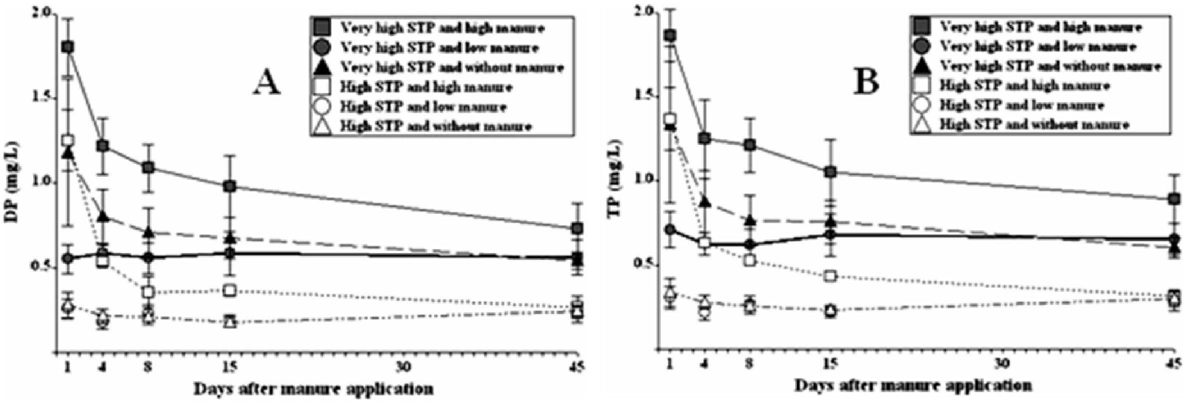

Figure 2. Temporal trends in dissolved P and total P as influenced by soil test P and manure application level for Ultisols.

The data indicate that by day 30 of the incubation, enough P was fixed in the soil so that P concentrations in runoff were reduced in soils that did not have runoff, relative to those soils in which P was being lost from soil solution by sorption and precipitation reactions as well as the P lost via surface transport in runoff. Runoff P concentrations were reduced primarily by P sorption and precipitation reactions (occurring from day 1 onwards after experiment initiation) and to a minor extent by the losses of the most labile forms of P.

Increasing amounts of P were being fixed in the soils during the incubation period (Table 1). Increasing STP from "high" to "very high" and manure application, increased the degree of P saturation. Soils with "very high" STP level had a 27% increase in the degree of P saturation relative to those with "high" STP. Soils receiving manure had an 8% increase in the degree of P saturation relative to unamended soil. These observations indicate that the soil test P was a more important determinant of the degree of P saturation than the manure application.

Conclusions

Runoff concentrations of DP and TP were influenced by the main effects of STP and manure application. The soil test P value was a more important determinant influencing the nutrient concentrations in runoff than the manure application level. The reduction in DP and TP concentrations in runoff during consecutive rainfall events was primarily due to sorption and precipitation reactions and to a minor extent the losses of the most labile P fractions. Lack of rainfall for 30 days after manure application may be the most important management factor for reducing the P concentration in runoff.

Table 1. Degree of phosphorus saturation as influenced by the duration of the experiment, soil test P, and manure application.

	Soil test P [1]		Manure application	
	"high"	"very high"	unamended	amended
Time (days)	------------------------Degree of P saturation (%)------------------------			
1	29.7a	51.3 c	41.2 a	50.5 ab
45	36.4ab	63.9 c	45.4 a	55.7 b
75 [2]	44.3 b	64.6 c	47.8 ab	57.7 b

1 Soils with different letter within soil test P or manure application groups are significantly different (P<0.05).

2 The evaluation at 75 days was performed on soils that received manure, were not irrigated for 30 days and then received rainfall simulations at days 30, 32, 38, 45 and 74 days after manure application.

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Processes of P mobility from Fitzgerald river catchment following application of different p rates

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Abstract

Phosphorus (P) export by erosion, surface runoff, throughflow and leaching are considered the main sources of P loss from agricultural land. The present study was conducted on the upper Fitzgerald River Catchment in the South coast region of Western Australia (WA) to examine the process of P mobilization at different P rates (0, 20 and 40 kg P/ha). Intact column leaching, packed box and field runoff plot studies were conducted on contrasting soils from the catchment. Soil solution was collected at 5, 10 and 15 cm by installing Rhizon soil solution samplers, and leachate collected at 30 cm. Runoff and soil solutions were analysed for particulate P (PP), dissolved reactive P (DRP), and total dissolved P (TDP) and dissolved organic P (DOP) was calculated by difference (TDP-DRP). Overall, DRP comprised <35 % of TP in runoff while about 90% or more of relative P losses via runoff, throughflow and leachate were in DOP and PP forms. The DOP and soluble organic carbon (SOC) in soil solution were well correlated in sand ($R^2 = 0.78$, $P < 0.05$) and clay soils ($R^2 = 0.56$, $P < 0.05$) at 0-5 cm suggesting that amounts of organic matter dissolved in soil solution influences P sorption and mobility. The higher PP concentration for the clay soil at the interface of clay and sandy layers indicates subsurface lateral flow is exacerbated by dispersive clay which might be an additional concern regarding P mobility in clay and duplex soils of the catchment. Ponding of water at the surface or lateral movement of water at the interface of sand and clay layers in the profile would increase the risk of P losses in the form of DP or PP in dispersion-prone sodic soils.

Key Words

Subsurface flow, hydrological risk, eutrophication, colloidal P, colloidal organic compounds.

Introduction

Phosphate fertilizers played an important role in the agricultural development of the south west of WA but continuous use of P fertilizers for several decades led to a gradual build up in soil P (Samadi and Gilkes 1998). These accumulated P inputs coupled with recent adoption of minimum tillage for crop establishment and a strong affinity of soils for P, results in the accumulation of P near the soil surface, where it has the greatest potential for P loss though overland flow (Sharpley 1995). Most of the research on understanding this process of P loss from agricultural land in WA has concentrated on identifying the sources and processes of nutrient export from pasture land in the coastal zone to wetlands, estuaries and streams (McKergow *et al.* 2002). In contrast, very little research has been carried out on the nutrient export from cropping land in medium to low rainfall zones (Weaver *et al.* 2003) where fertilizers account for much of the agricultural nutrient inputs. Until recently, study of the impact of management programs on nutrient delivery at the catchment scale was very limited. However, modeling by Weaver *et al.* (2003) and Wong *et al.* (2006) for catchments on the south and west coast of Western Australia has begun to address these issues. Phosphorus is transported from soil to surface water in two major forms, DRP and PP, from agricultural land by runoff, erosion and leaching (Sharpley 1985a). Studies have reported that runoff generation in the south west of WA is dominated by throughflow and George and Conacher (1993) found that runoff mechanisms on a small hill slope near Narrogin were dependent on the extent and development of variable source areas of the catchment. Phosphorus export to surface waters via leaching (as opposed to erosion and surface runoff) is also an important source of P loss from soil to water (Hesketh and Brookes 2000). To quantitatively study the effects of soil type on P transport from cropping landscapes in the South coast region of WA, this study was carried out on intact columns, field runoff plots and packed boxes. The present research was thus designed to understand: (1) the mechanisms of P transfer to surface waters (either by runoff, throughflow or leaching) either in solution or attached to suspended sediments and (2) effects of rates of P application on P loss.

Methods

Study site characteristics

This investigation was conducted on the upper Fitzgerald River catchment, 400 km south east of Perth. The catchment covered an area of about 104,000 ha and has a Mediterranean-type climate with annual rainfall 400 to 450 mm (Hill and Schiller 2003). The soils in the catchment are classified as: Hypocalcic Mottled-Hypernatric Brown Sodosol; Acidic-Sodic Magnesic Brown Dermosol; Hypocalcic Petrocalcic Black Sodosol; Mottled-Sodic Eutrophic Brown Kandosol; Eutrophic Mottled-Mesonatric Brown Sodosol; Eutrophic Mesonatric Brown Sodosols (McArthur 2004).

Sampling

Intact soil cores (10 cm diameter × 20 cm length) were collected from moderate P-loss risk areas of the catchment from sand, clay and loam soils. The cores were irrigated with 25 mm of water (196 ml of deionised water per column) at 4-day intervals and a total of 20 irrigations were applied to each core. The packed box study was conducted on galvanized steel boxes constructed from sheet metal with dimensions of 100 cm (length) x 40 cm (width) x 30 cm (height) to collect runoff and throughflow at 10 and 30 cm depth. Simulated rainfall was applied at 100 mm/hr, which represents the intensity of storm events similar to those which occur in the rainy season at the catchment. Simulated rainfall was applied to the boxes at 1, 15 and 30 days. Rhizon soil solution (< 0.1 µm pore size) samplers were installed horizontally in the columns and runoff boxes at 5, 10 and 15 cm depth. The soil solution was removed periodically under vacuum and transferred immediately to a freezer at -20ºC. Twelve field runoff plots each measuring 2.0 x 1.5 m were installed in the upper Fitzgerald River catchment in February 2007. Runoff from all plots was collected in 2007 after two rainfall events through collection devices consisting of 70 L containers capable of containing 20% of runoff from rainfall events up to 50 mm rainfall. A trench was dug perpendicular to the slope direction and equipped with collectors to collect separately overland (surface runoff) and throughflow (lateral through the soil profile). Barley seed was drilled in the plot in May, 2007 with three rates of phosphate fertilizer (0, 20 and 40 kg P/ha as DAP), giving four replicates of each P treatment.

Laboratory methods

The pH and EC were measured for all samples and solutions were then filtered through a 0.45 µm membrane filter for DRP, TDP and SOC. Dissolved OP was calculated from the difference between TDP and DRP. Total solids (TSS) were determined by oven drying 20 ml of runoff and through flow samples at 105ºC for 24 hrs. Particulate P was determined by the difference between TP (unfiltered) and TDP concentration. The statistical analysis was carried out using Statistic 8 software.

Results

Runoff

The DRP load for sand and clay soil was <0.26 mg (4-25% of TP) and 0.04-1.10 mg (2-67% of TP) irrespective of events and increased with P rates ($P < 0.05$). The amount of DOP for sand and clay varied from 0.14-0.71 mg (2-80% of TP) and 0.06-1.19 mg (16-72 % of TP), and significantly increased with P rates ($P < 0.05$). Higher relative P loss in PP (> 68 %) forms was observed for runoff losses whereas DRP (< 49%) and DOP (< 35%) were lesser contributors to P transport in runoff (data not shown). In the field simulation study, DOP load was a major proportion (51-87%, data not shown) of TDP in runoff. Significantly higher P load occurred for broadcast P fertilizer application relative to drilled fertilizer ($P < 0.05$).

Throughflow

The amounts of DRP in sand and clay soil ranged from 0.01-0.47 mg and 0.04-3.24 mg (1-63% of TP) whereas DOP varied from 0.02-0.38 mg and 0.48- 17.7 mg (30-90% of TP). The PP ranged from 0.01-0.15 mg and 0.05-2.01 mg (2-58% of TP) for sand and clay. In sand soil, the amounts of DRP and DOP transported in throughflow at 30 cm varied from 0.01-0.81 mg (4-11% of TP) and 0.21-7.61 mg (68-90% of TP) and an increase in DOP as a percent of TP occurred with subsequent runoff events. Significant increase in DRP and DOP concentrations occurred with P rates of application but no effect of surface soil slope on these P forms was observed in sand soil ($P < 0.05$). Major P losses occurred as DOP (< 90%) and PP (< 35%) forms in leachate of sand whereas DRP constituted < 25 %. Similarly in clay soil, DRP and DOP loads ranged from 0.02-2.00 mg (3-27% of TP) and 0.07-3.20 mg (26-70% of TP), respectively, and P load increased significantly with P rate ($P < 0.05$). Greater relative P loss occurred in throughflow as DOP (< 68%) and PP (< 84%) compared to DRP (< 34%, data not shown).

Phosphorus concentration in leachate

Dissolved OP (1.2-53 mg/l) was a major fraction of TDP in the leachate followed by DRP (0.05-6.7 mg/l) in sand. Although similar trends were observed with clay and loam, the TDP concentration was low compared to sand ($P < 0.05$) and the values varied from 0.2-9.5 mg/l and 1.4-23 mg/l, respectively. The leachate obtained from clay and loam soils was highly turbid unlike in sand. Columns of clay generating turbidity with leaching events often became blocked after the 7th event. A higher percent of P was leached and a lower percent was retained in sand (18.6 %) and loam (14.8 %) compared to clay (7.1%) at the higher P application rate.

Leaching losses

Initially soil solution without P application (control) had a DRP of <2 mg/l but with increased P application an increase in P concentration was found regardless of soil type ($P < 0.05$). With the increase in time of contact of fertilizer with soil, P concentration decreased in sand soil and to a lesser extent in clay and loam soil. Dissolved OP constituted the main proportion of TDP in soil solution at depth after application of inorganic P. Significant increase in DOP concentrations occurred with higher rates of P application at 5 cm (533 mg/l and 400 mg/l) compared to DRP ($P < 0.05$) in sand and clay soil of the box study

Discussion

Runoff losses of P

The high proportion of TP lost as DOP and its stronger relationship with TDP compared to DRP ($P < 0.01$, $R^2_{sand} = 0.81$, $R^2_{clay} = 0.79$) suggest that the DOP fraction was the major dissolved P form lost in runoff. Runoff TP concentrations were linearly related with PP ($P < 0.01$, $R^2_{sand} = 49$, $R^2_{clay} = 0.35$) in both soil types in the box study reflecting the important contribution of PP to TP concentration in runoff which is consistent with the findings of Kleinman *et al.* (2004). The concentration of P in the runoff was increased after P application as observed in the field simulation but was higher with broadcast P application than drilled P ($P < 0.05$). Hence, the conventional practise of broadcasting P fertilizer on the soil surface during the summer months appears to be inherently more risky in terms of run-off P transport to streams than P application by drilling for crop production.

Throughflow P losses

The throughflow volume generally depends on topsoil texture and the degree of porosity contrast between topsoil and subsoil (Stevens *et al.* 1999). Sediment can be readily transported below the soil surface as dispersed particles. Higher ESP of the subsoil and increased turbidity of throughflow with rain events for the clay soil indicate that dispersion is contributing to PP transport in throughflow. The throughflow samples collected from the clay soil were highly turbid for initial rain events, which most likely was due to the higher internal erosion in macropores. A higher proportion of PP was found for the clay soil at depth in comparison to the sand, therefore subsurface lateral flow along the interface with dispersive clay might be a source of P mobility in the clay soil. The hydraulic behaviour below 10 cm in clay soil largely depends on the amounts and nature of the clay minerals present, soil structure and the levels of exchangeable Na and ESP.

Phosphorus leaching losses

The rate of applied P fertilizer was the major factor influencing P leaching losses from sand and clay soils under leaching conditions both in field and box studies ($P <0.05$). Below 5 cm, P leaching was slow in the clay soil, which might be due to slow water movement, reduced macro porosity and increased sorption of DRP. The concentration and total amount of P moving in DOP form in the leachate was significantly larger than DRP in the column leaching, field run-off plots and the packed box. The runoff, throughflow and leachate were dominated by colloidal organic materials (DOP). The DOP fraction may contain fine (< 0.45 μm in filtered samples and <0.1 μm in soil solutions) quartz, mica, kaolinite and chlorite minerals which are potential inorganic carriers for DRP. On the other hand, DOP in soil solution (< 0.1 m) might be associated with fine colloidal compounds such as silicates, metal hydroxides, humic acids, polysaccharides, fulvic acids and proteins. It was evident from the dark colour of soil solution and its high SOC concentration at depth in the soils that a potential organic carrier of P exists in mobile water, even though the exact composition of it remains unresolved. In addition to DP, P bound to suspended particles and colloids contributes to P leaching from agricultural soils (Motoshita *et al.* 2003). Phosphorus may be bound to mineral colloids, such as Fe and Al oxides, or to organic or organo–mineral colloids (Hens and Merckx 2002). Colloidal P in soil solution accounted for about 13 to 95% of TP, but its relevance for P leaching and the processes governing its release from soils are not fully understood.

Conclusion

The P load in mobile P forms increased with increasing P rate in column leaching, packed box and field studies. Under field conditions, higher P loss occurred with broadcast P application compared to drill placement. A high proportion of TDP was in the form of DOP in runoff and throughflow (at 10 and 30 cm depths). The significant correlation between DOP and SOC in soil solution of sand and clay soils at 0-5 cm depth suggests that the amount of organic matter dissolved in soil solution influences P sorption and mobility. The relatively higher affinity of soil for DRP compared to DOP might allow soluble organic P (DOP) to be more mobile through the profile in association with colloidal compounds <0.1 µm. Overall, DRP comprised <35% of TP in runoff while about 90% or more of relative P losses via runoff and leachate were in DOP and PP forms. The higher PP concentration for the clay soil at the interface of clay and sandy layers indicates subsurface lateral flow is exacerbated by dispersive clay which might be an additional concern regarding P mobility in clay and duplex soils of the catchment.

Acknowledgements

This work was co funded by the Australian Grains Research and Development Corporation as part of its Nutrient management Initiative. We are grateful to the Fitzgerald River Catchment Demonstration Initiative and growers in the catchment for helping with this work.

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Recovering soil structure by management practices in a sandy clay loam Acrisol degraded by agricultural use

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Abstract

Soil use for agricultural production may increase soil structure quality as long as conservation management practices are adopted. The aggregates and single particles distribution into diameter classes (9.51-4.76, 4.76-2.00, 2.00-0.25, 0.25-0.053, <0.053 mm) and carbon (C) stocks in the surface layer from 0-7.5cm were studied to evaluate the contribution of management practices in the soil aggregation recovery of a physically degraded soil. The management system was a degraded soil (cropping system), using the native condition (rangeland) as a reference in a sandy clay loam Acrisol in Rio Grande do Sul, Brazil. The intense tillage and the low addition of residues for 30 years decreased the proportion of aggregated soil (76.4% in the Rangeland to 49.9% in the Cropping system) and increased single particles (23.6% to 50.1%). C stock decreased from 20.0 Mg/ha in the rangeland to 11.8 Mg/ha in the cropping system. From a degraded soil condition, the no-till system with higher diversity of plant species and the addition of residues increased the proportion of aggregated soil from 49.9% (cropping system) to 70.7% over a 15-year period. The macroaggregates (>0.25 mm) also were increased from 22.8% to 53.5% and the C stock reached 17.9 Mg/ha building a complex soil structure with the capacity to increase soil quality.

Introduction

Aggregation is an essential property for the soil to be able to fulfill its roles and ensure quality (Doran and Parkin 1994). It is related to the soil's ability to offer an adequate balance between water and air for the development of plants and soil organisms and to regulate and compartmentalize the flow of water and nutrients in the biosphere. Soil aggregates are built in a combination of two processes involving the interaction between minerals, polyvalent cations, organic matter, microorganisms, plant fragments, and roots of living plants (Edwards and Bremner 1967; Tisdall and Oades 1982; Miller and Jastrow 1990; Golchin *et al.* 1998). In one processes, the construction of a hierarchy of structures occurs. First, the microaggregates (< 0.25 mm) are formed by the repeated interaction between organic molecules, polyvalent cations, and mineral particles from the clay fraction (Edwards and Bremner 1967). Next, the macroaggregates (> 0.25 mm) are formed by the mechanical union of microaggregates during the growth of roots of living plants and hyphae of rhizosphere fungi (Tisdall and Oades 1982; Miller and Jastrow 1990). Decomposing plant fragments and bacterial colonies build macroaggregates through the interaction with microaggregates and single particles (Golchin *et al.* 1998). Therefore, in addition to intrinsic soil characteristics (texture and mineralogy), agricultural management practices interfere directly with soil macroaggregate building by their influence on organic matter, microorganisms activity and plant root development.

Under native conditions, the soil becomes organized over time into well defined structures, due to its granulometric and chemical composition and to the action of biological agents. The conversion from native condition into conventional agriculture causes dramatic changes to that stable state, which result in losses of organic matter and water-stable macroaggregates. However, the adoption of conservation practices based on minimum till and adequate residues management may prevent organic matter degradation and maintain or recover soil structure. In this work, we study the recovery of soil structure by management practices in a sandy clay loam Acrisol degraded by intensive agricultural use by analyzing aggregates and single particles proportions and soil stock carbon.

Methods

The management systems studied are part of a long-term experiment conducted at the Agronomy Experiment Station, Federal University of Rio Grande do Sul, located at 30°50’52”S and 51°38’08”W (Weber and Mielniczuk 2009). The soil is classified as an Acrisol, with 300 g/kg coarse and medium sand (2.0 to 0.2 mm), 237 g/kg fine sand (0.2 to 0.06 mm), 211 g/kg silt, and 253 g/kg clay (Silva 1993); kaolinite (720 g/kg) and iron oxides (109 g Fe_2O_3/kg) are the dominant minerals in the clay fraction (Bayer *et al.* 2001).

Characterization of the experimental area and management systems

Originally, the experimental area was rangeland. From 1969 to 1983, *Helianthus annuus* and *Brassica napus* crops were grown using rotary tiller. In 1985, after liming and fertilization, an experiment was installed with three soil tillages and cropping systems in a randomized block design with three replicates. Four treatments without N application were studied: conventional tillage *Avena strigosa* / *Zea mays* (CT a/z), conventional tillage *Avena strigosa* + *Vicia sativa* / *Zea mays* + *Vigna unguiculata* (CT as/zu), no-till *Avena strigosa* / *Zea mays* (NT a/z), and no-till *Avena strigosa* + *Vicia sativa* / *Zea mays* + *Vigna unguiculata* (NT as/zu) (Table 1). In addition to the experimental plots, an adjacent area was sampled as a reference for maximum soil degradation condition (Cropping). This area had been cultivated since 1969 with cereals and conventional soil tillage, with plowings and disking conducted twice a year. The native condition (Rangeland) was sampled at three adjacent locations at the same elevation of the experiment area and the cropping area to serve as reference for the original condition (Table 1).

Table 1. Characterization of the management systems studied.

Management System Code	Crop Types		Soil tillage	Time under current management at 2000 (years)	C added by plants (Mg/ha/y)
	winter	summer			
Rangeland	mixed native grassland$^{(1)}$ with moderate grazing		none	indefinite	N.D.
Cropping	*Triticum aestivum* and *Avena strigosa*	*Zea mays* and *Helianthus annus*	plowing and disking	30	3.0$^{(2)}$
CT a/z	*Avena strigosa*	*Zea mays*	plowing and disking	15	4.23$^{(3)}$
CT as/zu	*Avena strigosa* and *Vicia sativa*	*Zea mays* and *Vigna unguiculata*	plowing and disking	15	7.52$^{(3)}$
NT a/z	*Avena strigosa*	*Zea mays*	no-till	15	3.92$^{(3)}$
NT as/zu	*Avena strigosa* and *Vicia sativa*	*Zea mays* and *Vigna unguiculata*	no-till	15	6.90$^{(3)}$

(1) Mixed grassland dominated by *Paspalum notatum* with *Desmodium spp.*, *Macroptilium spp.*, and *Stylosanthes spp.*

(2) Estimated value.

(3) Source: Lovato *et al.* (2004). Data already consider carbon added by roots.

N.D. = not determined.

Soil Sampling

Undeformed soil samples from the systems described in Table 1 were collected at a 0-7.5 cm depth in two seasons, September 1999 and September 2000. The soil samples were slightly broken with the fingers in order to obtain aggregates smaller than 9.51 mm in diameter. The aggregates were air-dried for 72 hours.

Distribution of Aggregates and Single Particles into Diameter Classes

The distribution of aggregates into diameter classes by wet sieving followed the methodology described in Carpenedo and Mielniczuk (1990). Single particles, which consisted of mineral quartz particles and concretions of non-associated minerals forming aggregates, were separated manually using a sharp instrument under the stereoscopic microscope at 2X (9.51-4.76 mm class), 10X (4.76-2.00 mm class), and 20X magnifications (2.00-0.25 mm class). The weights for each class were obtained. For the 0.25-0.053 mm class the aggregate and single particle frequencies within a 2 mm^2 field were counted under the stereoscopic microscope at 63X magnification. For the < 0.053 mm class, single particles were considered those with silt size (> 0.002 mm). The weights for those fractions were also obtained.

Carbon Stock Determination

Total soil carbon was determined by the Walkley-Black (Tedesco *et al.* 1995) and expressed as equivalent mass, so the soil density differences between treatments were compensated. The soil mass in each system was adjusted for soil mass in the native field, using the 1.50 Mg m^{-3} density determined in 1998 by Lovato *et al.* (2004).

Results

The native ecosystem (Rangeland) was predominantly covered with vegetation consisting of several grass species and a small frequency of winter legumes (Table 1). These systems had around 76.4% of aggregated soil and 23.6% of single particles, distributed among the various diameter classes (Figure 1a). From the aggregated soil, 51.7% were in classes > 2.00 mm, while single particles had their highest percentage in the 2.00 – 0.053 mm class, with 20.3% of the total soil. Such good structure is the result of a long and continuous action of the roots mainly of the grasses species (Bradfield 1937; Jastrow *et al.* 1998; Silva and Mielniczuk 1998) as well as the adequate carbon stock [20 Mg/ha in the 0 – 7.5 cm layer (Figure 1b)].

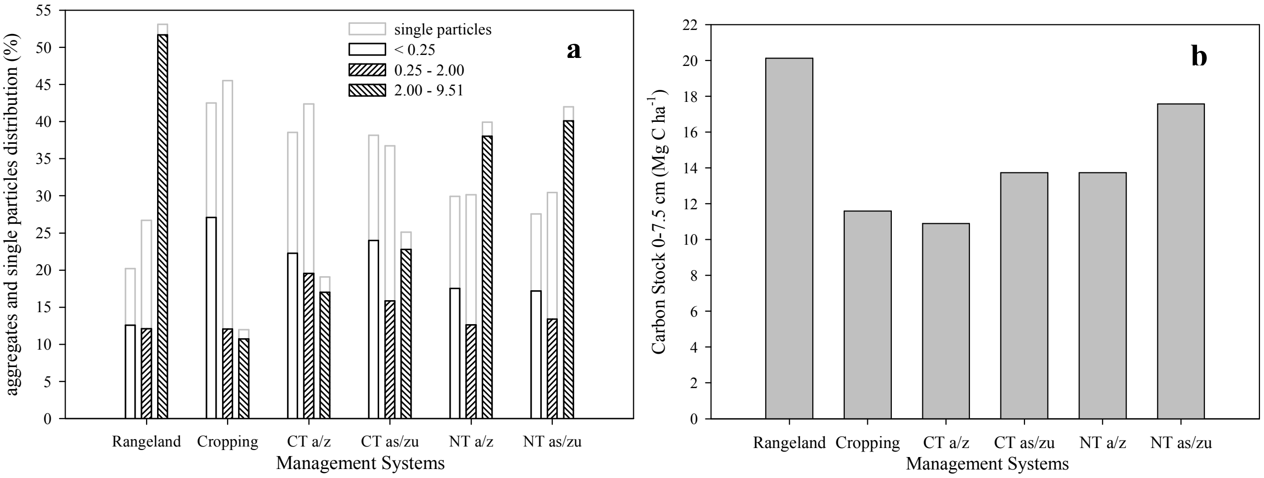

Figure 1. Aggregates and single particles distribution into diameter classes (a) and carbon stock (b) in the 0 – 7.5 cm layer in the management systems. CT = conventional tillage; NT = no tillage; a = *Avena strigosa*; z = *Zea mays*; s = *Vicia sativa*; u = *Vigna unguiculata*.

The inadequate soil tillage system used between 1969 and 1983 (Cropping) decreased the aggregated soil to 49.9%, and aggregates with diameter > 2.00 mm from 51.7% to 10.7% (Figure 1a), while single particles increased from 23.6% to 50.1%. From that degraded soil structure, management systems were implemented (Table 1) in order to restore the structure to its original condition. So the reduced soil tillage, the carbon added via plants and the number of plant species improved the soil quality. The CT a/z system represents a decrease in soil tillage to once a year and a increase of carbon added (Table 1) in relation to the initial degraded condition (Cropping). This condition provided an increase in the total proportion of aggregates and a change in the distribution (Figure 1a). There was a tendency for aggregates < 0.25 mm to become organized into larger aggregates, even incorporating single particles into the structure, a fact that was demonstrated by the difference in the distribution between CT a/z system and Cropping system for the 2.00 – 0.25 mm class. That behavior is a reflex of the organo-mineral interactions, due to the carbon added by the plants. The roots and hyphae of the rhizosphere fungi may also have contributed to improve soil macroaggregation in the CT a/z system. The CT as/zu system represents a improvement of the CT a/z system by the increase on plant species in each growing season and, consequently, the addition of carbon via plants cultivation. This practice increased the total proportion of aggregates by 3.8 % in relation to CT a/z. Aggregate distribution also changed. There was a tendency for aggregates < 2.00 mm to become organized into aggregates > 2.00 mm. The formation of those macroaggregates is the result of the mechanical action of roots, binding together microaggregates and smaller particles. In that process, single particles become part of the aggregates. The introduction of legume plants in both growing seasons in the CT as/zu system may have favored the process due to the better development of roots and hyphae of rhizosphere fungi in a condition of plant species diversity. Consequently, the proportion of single particles decreased in the 0.25 – 2.00 mm class in relation to CT a/z.

The NT a/z system represents the improvement provided by the no-till. This system shows the effect of the physical compression by the machinery traffic, in addition to the carbon added by plants and the action of the root system. The lack of soil tillage maintains the structures formed by compression; the added carbon favors organo-mineral interactions and consequently the formation of microaggregates, while roots provide the organization of smaller aggregates and single particles from classes < 2.00 mm into the 2.00 – 9.51 mm class. The resulting aggregation comes from biological action and has greater complexity. Also it increases the macro- and micropores and provides a suitable habitat for the development of organisms. The best management practice (NT as/zu) increased the number of plant species in each growing season and, consequently, increased the addition of carbon. Such improvement did not result in a difference in the proportion of soil aggregated and single particle distribution in relation to NT a/z. However, it is important to analyze the carbon stock over the development period of those systems. The NT as/zu system accumulated an additional of 3.9 Mg C/ha in the 7.5 cm surface layer in relation to NT a/z (Figure 1b). Therefore, both systems became organized with the same distribution of aggregates into diameter classes (Figure 1a) as a result of texture, mineralogy, presence of roots, microorganisms, and carbon, while a higher amount of carbon was found in the aggregate composition for NT as/zu. An equal distribution of aggregates with a higher carbon stock indicates that the structure of the aggregates is more complex and has more organic components, such as fragments of plant tissues and macroorganisms, hyphae and microorganism cells, and humic substances. The presence of carbon in the structure enables the soil to play its roles, ensuring soil quality, which makes a difference in favoring environmental sustainability by an agricultural production system.

Conclusion

Management practices with no-tillage increased the proportion of macroaggregates in relation to the initial condition. In the same way, the carbon added via complex cropping systems increased the proportion of macroaggregates. When those practices were applied jointly there was a significant increase in the proportion of macroaggregates in the soil mass and in carbon stock.

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Relationships between soil properties, erodibility and hillslope features in Central Apennines, Southern Italy

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Abstract

Soil erosion is one of the main environmental problems in the Mediterranean area. This problem is becoming even more important especially in the central Apennines, where several erosive processes, frequently favoured by intensive land use, occur due to the action of concentrated running water in few hours. To investigate on the relationships between soil characteristics and local morphologic-topographical features, a study was carried out in the southern part of Italy which is located in Molise region within the middle little valley (Trigno River). In the study area, a systematic sampling of topsoil was performed to evaluate by means of geostatistical techniques the relationships between soil erodibility and superficial soil structure, texture and organic matter content. The results show clear evidence about the relation between the topsoil characteristics and morphometric indexes. In particular, the differences in topsoil erodibilty appear to be directly related to slope morphology and to the specific morphodynamic features. The observed relationships reflect the possibility to better evaluate both the soil erodibility factor (K) used within the USLE equation and the spatial variability of physical and chemical soil characteristics on the basis of digital terrain analyses, and so better predict soil loss rates.

Key Words

Rainfall erosion, USLE Equation, soil erodibility factor.

Introduction

The progressively increasing exploitation of agricultural areas and the ongoing climate changes are largely favouring soil loss related on particular to the action of running water. As the susceptibility of soils to erosion depends on the complex interactions between geologic-environmental parameters and soil features, (which are also affected by modifications just due to the acting erosive processes), it appears particular important to ascertain their spatial variability in relation to slope features and local relief. Predictive methods to reliably estimate soil erodibility are generally based on the analysis of spatial variability of a few soil properties, such as soil structure, soil texture and organic matter content (Wischmeier and Smith 1978). Statistical methods such as kriging interpolation have been widely used in spatial prediction of physical and chemical soil parameters (Castrignanò *et al.* 1998; Diodato and Ceccarelli 2004). The effects of erosive processes on soil features and their consequent spatial distribution in relation to local morphologic and morphometric slope features, can be observed along a soil "catena" located along the slope profile (Birkeland 1999). On the basis of such considerations, to estimate on particular the relationships between soil features and erodibility, type and distribution of erosive processes and local slope features, a large-scaled analysis was carried out in a small test area located in southern of Italy (Molise) which is drained by the Rivo torrent. Within the test area, two soil "catena" have been developed to determine the main soil characters along an alignment crossing different morphologic slope units which are distinguished with reference to specific dominant erosive phenomena. Then, spatial statistical procedures were applied for spatial prediction of soil erodibility factor K (Wischmeier and Smith 1978) using the K topsoil sample values.

Methods

The studied area

The selected test area (about 2.67 km^2) has a test plot station for soil erosion measuring several climatic parameters, as well as soil erosion rates and liquid discharges in relation to different land cover (Aucelli *et al.* 2006a, 2006b). The geological substrate is made of clayey and marly-arenaceous rocks characterized by low permeability, above which mainly Vertisols and Inceptisols showing outstanding vertic characteristics have developed. Climate is characterized by mean annual rainfall and temperatures ranging respectively between 650 mm and 800 mm and 5° and 30°. Agriculture and pasture are the main economic activities. From a geomorphological point of view the study area shows a remarkable variety of hillslope forms and erosive processes, resumed on a map which classifies the whole territory into seven morphodinamic unit.

Pedological sampling

Ten soil profiles were samples along a 1.7 km long transect which defines two soil catenae extending from the valley. For each profile a detailed fact sheet was compiled. Moreover, soil samples taken from the main diagnostic horizons were subjected to physical and chemical laboratory analyses to the aim to classify the sampled soils according to FAO (2006). Systematic topsoil sampling was carried out on the basis of a net of sampling points (located at regular distances of about 300 m each one from another) in order to characterize the upper, about 20 cm thick, soil portion. Furthermore, also the spatial distribution of superficial bulk density and calcium carbonate content was analysed, as they can be considered good indicators of accelerated topsoil erosion.

Soil erodibility factor estimation

The values of the soil erodibility factor K of the topsoil samples were calculated using the following formula of Wischmeier and Smith (1978):

$$Ks = 2.1*10^{-4} (12\text{-}OM)\, M^{1.14}*3.25(S-2) +(2.5(P-3)/7.59*100 \qquad (1)$$

where K is expressed in t•ha•h/h•$MJ^{1.14}$•mm, OM represents the organic matter content (%), M defines the relations between percentages of silt, very fine sand and clay content (% silt + % very fine sand) (100 - % clay), S represents the soil structure code and P the permeability class. Spatial variability of the five examined parameters was evaluated by means of a geo-statistical analysis. The results were then compared to the spatial distribution of soil types and that of the morphodynamic units and, at last, to several morphometric parameters which were automatically extracted by a high resolution (5 m) Digital Terrain Model (DTM).

Results

The study area is characterized by ten different soil types. Figure 1 shows the pedological section, some basic soil characteristics are detailed in Table 1. The dominant soil types are Grumic Vertisols (some Calcaric) which represent about 60-70% of the test area.

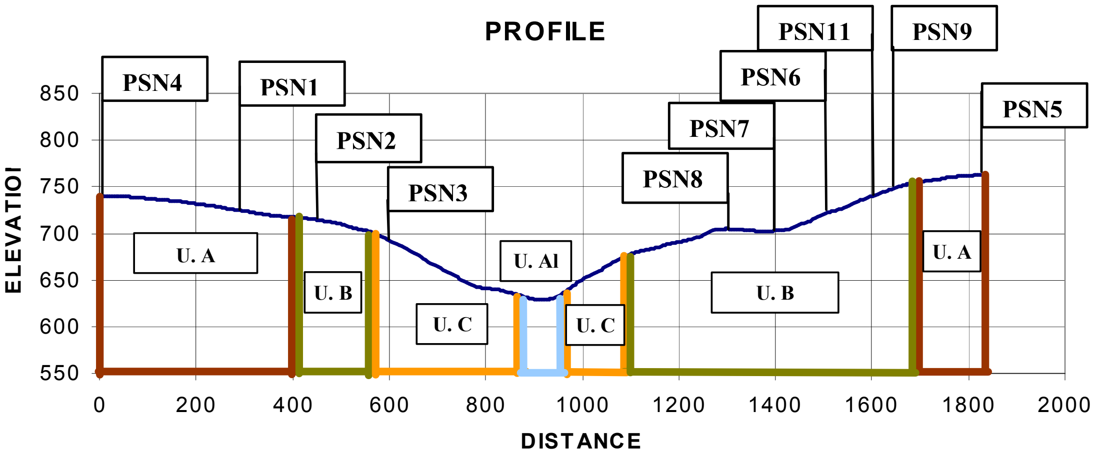

Figure 1. Topographic profile along the catena with indications about the location of soil profiles. Distances and elevations are expressed in meters. PSNx: soil profile code; Ux: morpho-dynamic unit.

All soil types have an organic matter content of less than 5.7% and most of them are poorly drained. Field and laboratory analyses showed that the soils along the transect can be classified as Grumic Mollic Vertisols (clayey and up to 1.5–2 metres thick, well structured, deeply fissured and characterised by a moderately deep calcic horizon), Vertic Calcisols (about 1 metre thick, with a superficial calcic horizon) and Leptosols (very thin soils with a massive structure and a strong sandy texture). Analyses of soil profiles along the catena have shown very clearly that the position of the profile on the slope, as well as type and intensity of local dominant hillslope processes acting there, are crucial for the development of diagnostic physical and chemical characteristics of soils. Spatial variability of the five examined parameters was evaluated by means of a geo-statistical analysis. The results show important correlation between their spatial distribution, soil types and he morphodynamic units. The soil erodibility map derived using a kriging interpolation is shown in Figures 2a and b.

Table 1. Some basic physical and chemical characteristics of soil profiles.

Profile code	FAO soil classification (2006)	Depth (cm)	Elevation (m)	Slope (°)	Lithology	Cracks (cm)	SOM (30cm)	Clay 30cm (%)
PSN4	Grumic MollicVertisols	210	739	0.38	AC	> 10	2.5	65
PSN1	Grumic Vertisols	160	723	4.59	AC	> 10	1.8	61
PSN2	Grumic Vertisols	125	713	4.90	AC	> 10	2.1	60
PSN3	Grumic Vertisols	120	688	15.35	AC	> 10	2.1	58
PSN8	Vertic Calcisols	45	703	16.90	CMC	3-5	5.7	41
PSN7	Grumic Mollisols	260	702	6.50	APC	-	2.3	21
PSN6	Grumic Vertisols Calcaric	150	715	16.30	AC	6-10	3.1	45
PSN11	Haplic Cambisols Calcaric	160	740	11.50	APC	> 10	1.3	26
PSN10	Haplic Cambisols Calcaric	210	746	11.50	APC	> 10	1.4	21
PSN5	Haplic Leptosols Calcaric	45	763	3.90	APC	3-5	2.2	13

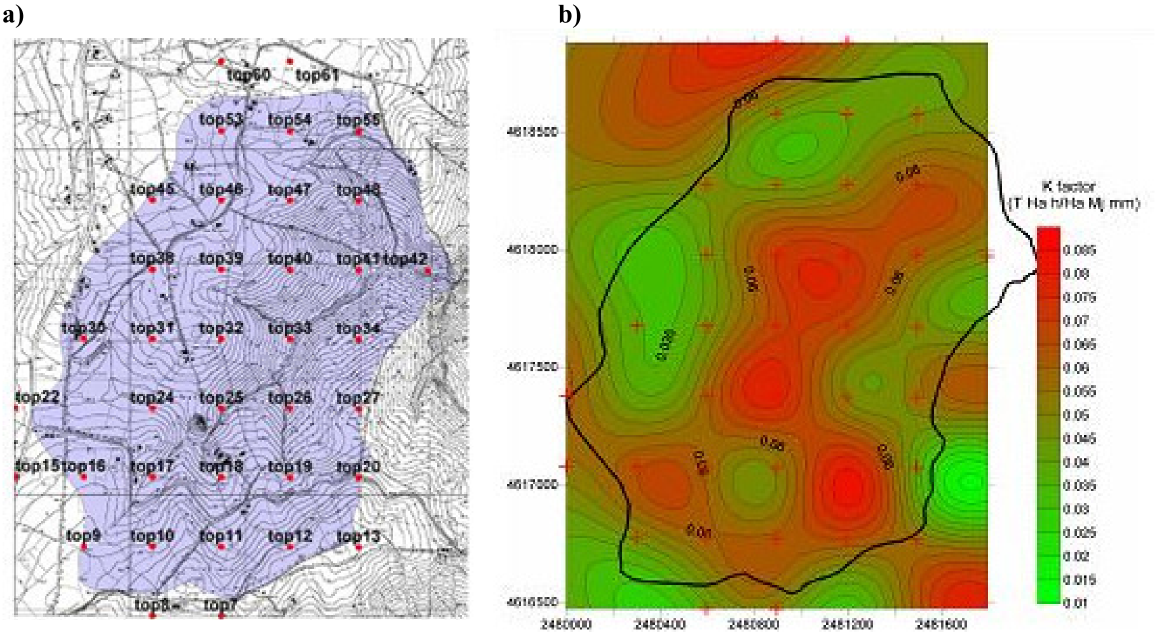

Figure 2. Location of topsoil samples within the test area a) and spatial interpolation of the K factor b), calculated by the formula of Wischmeier and Smith (1978).

The determined K values range from 0.01 to 0.085 t•ha•h/h•MJ•mm. The soil erodibility map shows significant differences of K values between the various examined soil profiles which depend on local soil variability. The spatial distribution of the K factor basically confirms that some of the chemical and physical properties of topsoils are clearly linked to the spatial distribution of certain morphometric indexes.

Conclusions

The results of the study encourage to develop methods and techniques to quickly and economically derive from DTMs some important soil characteristics whose estimate generally requires a lot of time and resources. The preliminary results will be useful for a more precise evaluation of the parameter K (soil erodibility factor) of the USLE equation and a better prediction of soil loss, and suggest important relationships between local geologic-environmental conditions, erosive phenomena, soil features and soil degradation.

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Removal of salts by *Atriplex nummularia* depending on soil moisture

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Abstract

The degradation of soils by the salinity and sodicity has been an important subject in the handling and use of soils, and its reclamation contributes with the improvement of the productivity and sustainability of the environments. Studying the phytoremediation of salt- affected soils with *Atriplex nummularia*, this study aims to determine the extraction of salts by plants grown in saline-sodic soil under conditions of water stress. The experiment was conducted in a greenhouse for 134 days cultivating *Atriplex nummularia* in pots containing 20 kg of saline-sodic soil at four moisture levels (35, 55, 75 and 95% of field capacity) , designed on blocks with eight replications, collecting plant and dividing it into leaf, stem and roots to determine the extraction of salts. The values of extraction of sodium by leaves + stem were 251.63, 277.84, 394,92 and 440,36 kg/ha 134 days^{-1} to 35, 55, 75 and 95% of FC respectively. Removal of Ca, Mg, Na, K and Cl by leaf + stem were 644.25, 757.81, 1058.55 and 1182.00 kg/ha at 35; 55; 75 and 95% of field capacity, making it an alternative for the phytoremediation of salt-affected soils in the semi-arid region of Brazil.

Key Words

Phytoextraction, salt-affected soils, halophytes, field capacity.

Introduction

Salinity and the sodicity are among the main causes of degradation of the soil in semi-arid environments, because they damage soil properties, plant development and the society, which culminates in serious social and environmental impacts. Recovery of these soils contributes to the improvement of productivity and sustainability of the ecosystems. Reclamation practices and efficient handling should be adopted, since these soils are a valuable resource for agriculture and cannot be neglected (Qadir *et al.* 2007). The use of halophyte vegetation is based on phytoextraction, that is a phytoremediation technique that uses species of plants that absorb and accumulate the sodium in the shoot, which can be removed and used for other purposes. Qadir *et al.* (2007) claim that the phytoextraction is an efficient strategy of recovery of saline-sodic soils, with performance comparable to the use of alleviation chemical. One of the factors that should influence the extraction of salts by plants is soil moisture, by increasing the vegetative growth and, consequently, the absorption of salts. This work determined the extraction of elements by *Atriplex nummularia* grown on saline-sodic soil under conditions of water stress (35, 55, 75 and 95% of field capacity).

Methods

The experiment was carried out in a greenhouse. We used sodic-saline soil collected from 0-30 cm depth, dried in air, homogenized and passed through a sieve of 4 mm before filling the pots. For physical and chemical characterization a -2mm subsample had 229 g/kg of coarse sand, 363 g/kg of fine sand, 327 g/kg of silt and 81 g/kg of clay, with soil bulk density of 1,40 kg/dm^3 ; soil pH(1:2,5) = 8,66; pH of the saturation extract = 7,45; electrical conductivity (EC) of the saturation extract = 42,56 dS/m; Exchangeable Na$^+$ = 3,31 cmol$_c$/kg; cation exchange capacity = 4,69 cmol$_c$/kg; exchangeable sodium percentage = 71,20%. Polyethylene pots were used with capacity of 20 kg of dry soil. Seedlings of *Atriplex nummularia* were used of 120 days age. The soil had a field capacity of 0.152 g/g. Pots were maintained at four moisture levels (35, 55, 75 and 95% FC). The treatments were disposed in randomized blocks with eight replications. The water used in the irrigation had EC of 0.75 dS/m. 134 days after the seedlings (DAS) the plants were collected and divided in leaf, stem and root, that were oven dried at 65 ºC for 48 h. The dried matter was ground subjected to nitricperchloric digestion to determine sodium, potassium, calcium, magnesium, zinc and copper. Chloride was determined by extraction in water and titration with silver nitrate (Malavolta *et al.* 1989). The results were analyzed through variance analysis and Tukey test ($P < 0.05$) using the Software SAEG 9.1 (UFV 2007).

Results

The dry matter of the leaves increased as a function of the soil moisture, with increment of 81% for the treatment with 95% of FC in relation to 35% FC, however, a decrease occued in the production of dry mass of stem and root for the soil at 95% FC, in relation to the treatment a 75% of FC (Figure 1).

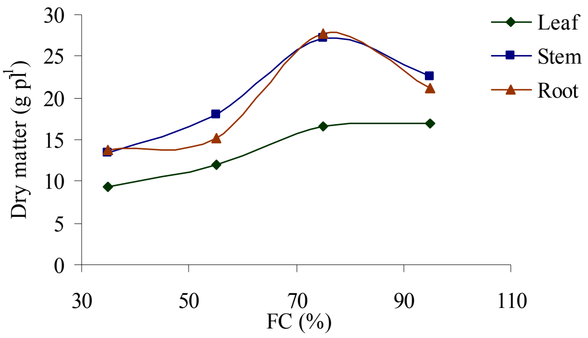

Figure 1. Dry matter production of parts of *Atriplex nummularia* as a function of soil water content.

The production of dry matter of stem + leaves were 3978.93; 5228.35, 7639.82 and 6925.11 kg/ha for 35, 55, 75 and 95% of FC, respectively. This biomass can be used as forage (Masters *et al.* 2007). The element content varied among the parts of the plant, with prevalence of chloride and sodium in the leaf, stem and root, followed by potassium and then calcium and magnesium (Table 1).

Table 1. Leaf, stem and root chemical composition of *Atriplex nummularia* grown in saline sodic soil

Element	Leaf	Stem	Root
Ca (g/kg)	5,24	1,55	3,40
Mg (g/kg)	6,13	1,13	2,50
Na (g/kg)	124,73	13,01	15,29
K (g/kg)	19,33	10,50	7,09
Cl (g/kg)	149,45	26,52	19,96
Cu (mg/kg)	1,03	0,35	7,84
Zn (mg/kg)	40,81	3,74	15,42

The leaf was the organ with the larger concentrations, especially for chloride and sodium, indicating the potentiality of use of the species in the phytoextraction of NaCl in soil-affected salts. The contents of Cu and Zn in the leaves were 1.03 and 40.81 mg/kg of dry matter respectively (Table 1). Norman *et al.* (2008) found values of Cu and Zn to leaves and small stems (< 3 mm) of *Atriplex nummularia* corresponding to 4.1 and 40 mg/kg of dry matter. Underwood and Suttle (1999) suggested that a diet for lambs should contain > 4 mg Cu/kg DM at highest rates of absorption and as much as 17 mg Cu kg DM^{-1} at lowest absorbability (Table 1).

The highest content of sodium and chlorine were removed by the leaves (Figure 2). The treatments 75 and 95% of FC removed more Na than for 35 and 55% FC. The contents of K were similar for the three fractions of the plant and there were not significant differences among the treatments, except for the stem. The same behavior of the sodium was observed for chlorine in the three analyzed fractions, with the largest content in the leaf, reaching 2.92 g/plant for the 95% FC treatment. The ratio of Na:K differed significantly among the treatments, that had larger values in relation to the stem and the root. The sodium removed by the stem + leaves were 251.63, 277.84, 394.92 and 440.36 kg/ha for 35, 55, 75 and 95% of FC. Leal *et al.* (2008), evaluating phytoremediation with Atriplex in the same soil type, cultivated in a greenhouse, found values similar of sodium content in the leaves to 130 DAS. In addition, Ravindram *et al.* (2007), evaluate the reclamation of a saline soil in India, verified that the halophyte species *Saueda* and Sesuvium *portulacastrum* removed 504 to 474 kg/ha of sodium chloride in four months, respectively. Considering removal of total Ca, Mg, Na, K and Cl by leaf + stem were found 644.25, 757.81, 1058.55 and 1182.00 kg/ha for 35; 55; 75 and 95% FC.

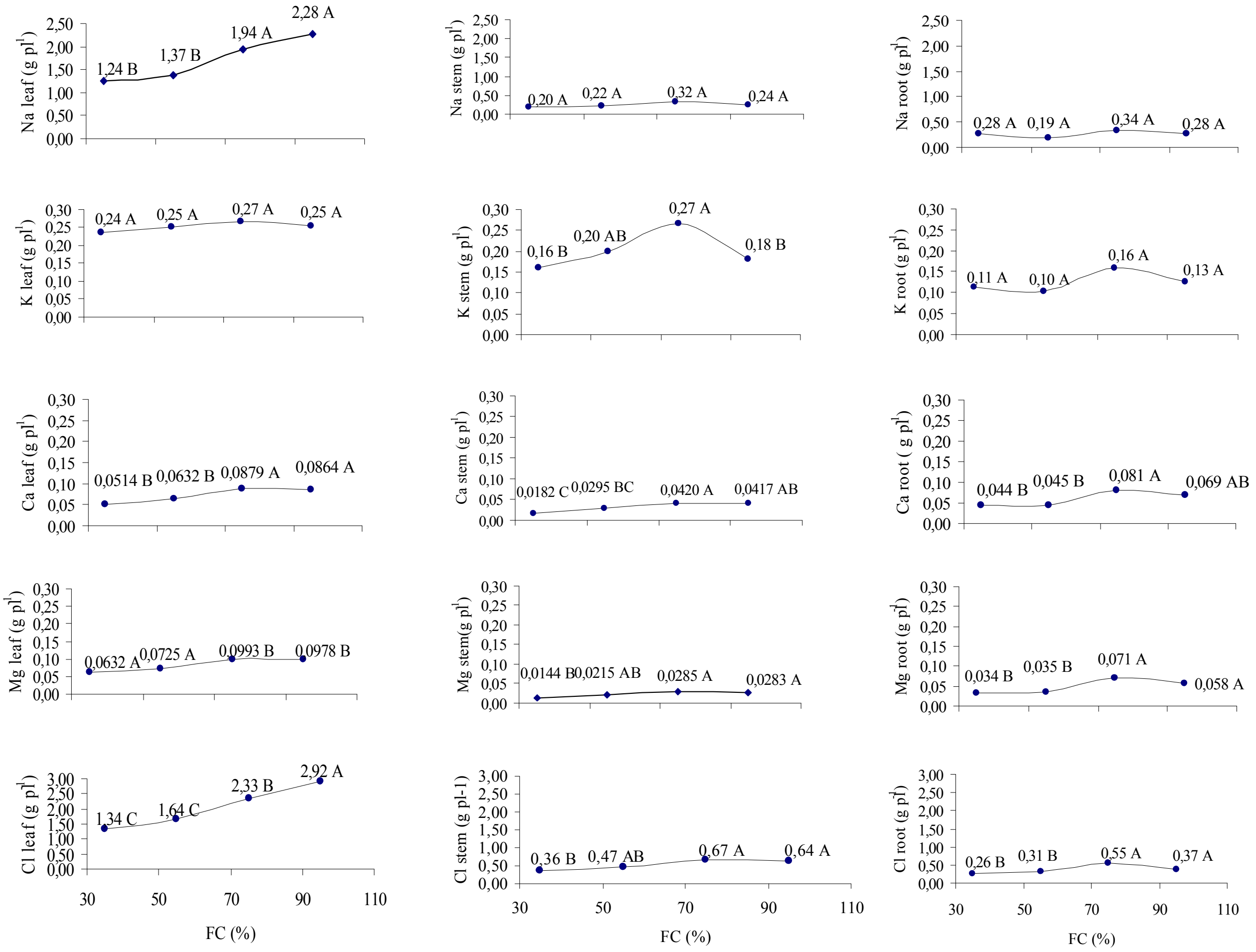

Figure 2. Sodium, potassium, calcium, magnesium and chlorine content in leaf, stem and root of *Atriplex nummularia* grown at salt-affect soil in Pernambuco (Brazil). Medium follow by same letter are no different by Tukey's test at 5% probability.

Conclusion

The production of dry matter by the leaf, stem and root was sensitive to soil moisture; The values of extraction of sodium by leaf + stem were 251.63, 277.84, 394,92 and 440,36 kg/ha 134 days^{-1} to 35, 55, 75 and 95% of FC respectively. Considering the removal of total Ca, Mg, Na, K and Cl by leaf + stem were found 644.25, 757.81, 1058.55 and 1182.00 kg/ha for 35; 55; 75 and 95% of field capacity.

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Research on the Relative Yields as Affected by Soil Moisture and Maize Planting Density

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Abstract: The thesis discussed the changes of soil moisture in maize fields at 2 representative experimental areas in the Songliao Plain, also the relations between soil moisture and yields, soil moisture and density, yield and density etc. It clarified that the most deficient soil moisture was in May under these experimental conditions, and from June to September, the soil moisture was slightly surplus. The yield increase potential of water supplement under different conditions were demonstrated. Coupling equations between soil moisture and density were established which provide a practical reference basis for maize planting in similar areas.

Key words
Maize, densities, soil moisture, yields.

General situations of the research area

Gongzhuling City and Changling County were chosen as experimental areas, the two areas are located at the main production area of the maize belt in China, and have semi humid and semiarid climatic environments. Their average annual precipitation is between 450 mm and 550mm. During the maize growth period, spring is arid; rain fall is concentrated in summer with less rain fall in autumn. The soil at Gongzhuling City is a black soil and that at Changling County is a black chernozem.

Experimental design

Gongzhuling experimental area:

(1) Density: 4 treatments of 45000, 55000, 65000, 85000 plants per hm2. Repeat the experiment 3 times. Plants were randomly arranged.
(2) Water supply: The total water supply amount (including precipitation and irrigation water) in the growth period were: 334mm, 426mm, 500mm, 600mm. Supplied artificially 5 times.
(3) Fertilization and maize varieties: The nutrients applied were: $N:P_2O_5:K_2O=215:92:60$ kg/hm^2. The maize varieties were Jidan 159 and Jidan 209.

Changling experimental area:

(1) Density: 4 treatments of 45000, 55000, 65000, 85000 plants per hm2. Repeat the experiment 3 times. Plants were randomly arranged.
(2) Water supply: The total water supply amount (including precipitation and irrigation water) in the growth period depended on total natural precipitation in the growth period. The target amount was 540mm.
(3) Fertilization and maize varieties: The nutrients applied were: $N:P_2O_5:K_2O=255:80:40$ kg/hm^2. The maize varieties were Yedan 19 and Simi 21.

Experimental methods

During the growth period of maize, soil samples from the soil layers of 0-20, 20-40, 40-60, 60-100 cm were collected from each plot; a drying method was used to determine soil moisture content. Statistical analysis was used to study soil water under different maize planting densities.

Results and discussion

By statistical analysis (Figure 1) the least precipitation months are April and May during the growth period with merely 42.8 mm, accounting for 10% of annual precipitation, which is the peak period of water deficiency, and seriously affected keeping a whole stand of seedlings and restrained maize growth. Local meteorological data reported probability of 30 mm or less precipitation in spring in the area reached 70% or more. The precipitation in June, July and August was 302 mm; accounting for 71% of annual precipitation, the precipitation in September was 41.7 mm, accounting for less than 10% of the annual precipitation.

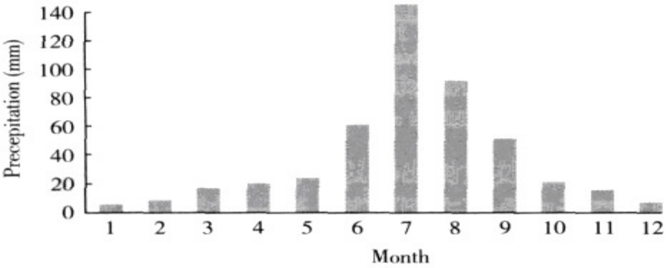

Figure 1. Precipitation distribution

A [illegible] itoring at the 2 experimental areas (table 1), in Gongzhuling experimental area, the precipitation in the whole growth period was 486.7mm, in spring the deficiency of soil water storage was 26.3 mm, in summer the surplus was 29.8 mm, in autumn the deficiency was 14.5 mm, and in the whole growth period, soil water storage was at the deficient state, the deficiency was 11 mm, and the water deficiency in subsoil was most serious. Under the circumstances of the planting density of maize of 55,000 plants/hm^2, the required water amount was 539 mm, thus the water deficient amount was 176 mm, thus soil water was deficient in spring, surplus in summer and was deficient in autumn.

Table 1. The change of soil water in the whole growth period of maize

Gongzhuling experimental area	Month	March-May	June-August	September-October	Total amount
Precipitation	mm	89.9	313.3	83.5	486.7
Soil layer 0-30 cm	mm	-2.0	+4.5	-3.9	-1.4
Soil layer 30-60 cm	mm	-8.7	+9.9	-4.0	-2.8
Soil layer 60-100 cm	mm	-15.6	+15.3	-6.6	-6.9
Soil water surplus and deficiency in all layer	mm	-26.3	+29.8	-14.5	-11.0
Changling experimental area	Month	June-July	August	September	Total amount
Precipitation	mm	122	108.5	132.4	362.9
Consumed water amount in all layers	mm	397.4	84.9	56.6	538.9
Soil water surplus and deficiency	mm	-275.4	23.6	75.8	-176.0

The relationship between moisture and density

When 330 mm of water was supplied, the changes of soil water contents did not show changes with changes maize density.

Under the circumstances of water supply being more 426 mm only the density of 85,000 plants/hm^2 showed that moisture content is not enough for maize growing.

In Changling experimental area, under the same water supply circumstances, in soil layers of 0-40cm and 0-60cm, the soil water contents gradually increases in June, July and August, then reduces from high to low from August to October; the relationship between plant density and soil water content was not strong in soil layer 0-60cm; it showed significant effect of density and soil water content in the soil layer under 60cm.

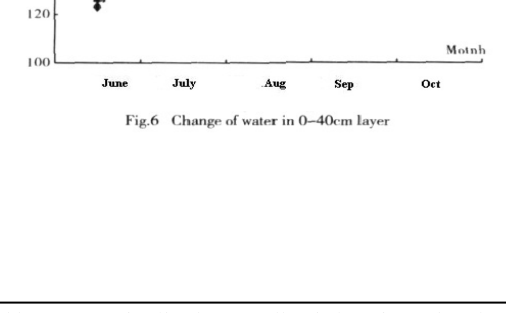

Fig.6 Change of water in 0–40cm layer

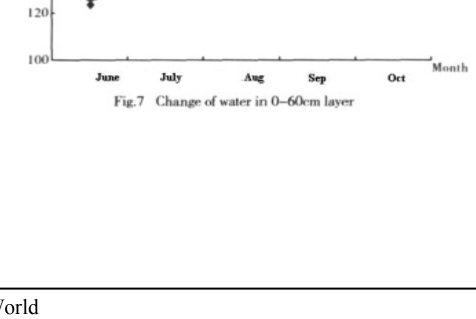

Fig.7 Change of water in 0–60cm layer

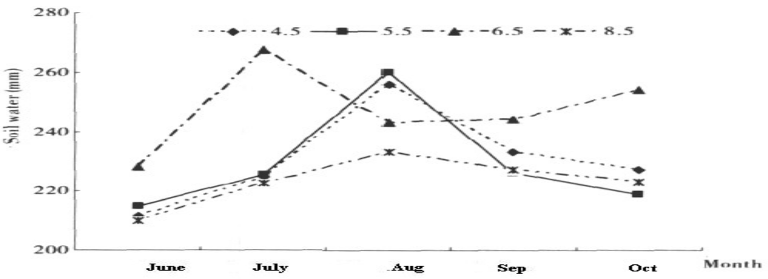

Fig.8 Change of water in 0–100cm layer

The relationship between water and yield

Water supply increased crop yield in from 9.0% ~ 43.4%. The yield increase effect of water supply treatment under 60000 plants per hm^2 were the best, the yield for water supply treatment was 1.4 times as much as that of the no-water supply treatment.

The relationship between yield and density

The maize yield of the maize variety Yedan 19 did not change remarkably with the increase of plant density, the yield at the lower density of 55000 plants per hm^2 was the highest and the yield increase was by 7.1%. The yield of Jidan 159 was reduced as its density increased, the yield for the lower density of 45000 plants per hm^2 was greatest and the yield increase was 20.7% (Table 2).

Table 2. Yield differences under different water conditions

Density	(plant/hm^2)	50000	60000	increase
no-water supply	（kg/hm^2）	6275	6300	0.4%
water supply	(kg/hm^2）	7226	7580	4.9%
Yield increase by water supply	%	15.2%	20.3%	

Analysis of the coupling relations between water and density

Density (x) and yield (y) regression equations are as follows:

Under the conditions of total soil water supply amount being 600mm (R^2=0.9593)

Y= -185X2 + 2090X + 2853.

Under the conditions of total soil water supply amount being 500mm (R^2=0.8247)

Y= -264X2 + 3107X + 1082.

Under the conditions of total soil water supply amount being 426mm (R^2=0.8865)

Y= -58X2 + 477X + 3907.

Under the conditions of total soil water supply being 334 mm (R^2=0.9680)

Y= -61X2 + 499X + 3233.

Conclusion

(1) Changes of soil water: The changes of soil water in the two experimental areas maize fields showed water deficiency at the more arid Changling experimental area was more significant. The temporal distribution of precipitation showed that it was arid in spring, surplus in summer and arid in autumn.

(2) Soil water and density: In the Gongzhuling experimental area and under the circumstances of different water supply, the soil water contents for the 3 densities of 45000, 55000, 65000 plants/hm^2 showed consistent changes from high to low, and then from low to high as maize was growing. Only soil water content of the higher density of 85000 plants per hm^2 showed the changes from low to high, from high to low and at last from low to high. In the Changling experimental area, the supply of soil water in all the layers were different due to different planting densities. In the soil layers of 0-40 cm and 0-60 cm, changes of soil water were not directly related to planting density, the change of soil water in deeper layer of 60-100 cm was closely related to planting density. To conclude that under the circumstances of different water supply amounts, the soil water in the deep layers was related to density. The density of 55000 plants per hm2 was the critical planting density affecting soil water.

(3) Soil water and yield: the amount of soil water directly affected maize yield; the highest yield for the water supply treatment was 1.4 times that for the non-water supply treatment.

(4) Yield and density: In a certain density range, the maize yield was increased with increase of density, but the yield potential of lower density was the greatest, and the yield was increased by 20.7%. There is close relationship between yield and density and the choice of appropriate density is very important.

(5) By simulating the coupling of soil water and planting densities the following information was found: The relations between total soil water supply amount (including precipitation and irrigation water amount) and planting density just has a “S” shape with 3 sections. In the semi-humid and semi-arid Gongzhuling maize planting area, when the total soil water supply amount was less than 400mm and more than 500mm, the upper and lower limits of the planting density of Yedan 19 is between 40000 and 60000 plants per hm^2 respectively. When the total soil water supply amount was between 400mm and 500mm, the maize planting density was linearly positively related to the water supply amount.

Runoff and water quality from steep hills in south-eastern Australia

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Abstract

To understand the mechanisms of surface runoff and the impact of phosphorus (P) fertiliser on runoff quality, a 4-year catchment study was conducted near Ararat in western Victoria. Four small catchments and two larger catchments with slopes of 9-33% were selected in the upper Hopkins basin. Superphosphate was applied at 40 kg P/ha once to two of the small catchments, and water quality samples taken from all the small catchments. Soil moisture was measured by a neutron moisture meter and reflectometers. Each surface runoff event was classified into terciles based on antecedent soil moisture. In four of the catchments, more flow occurred in the dry or intermediate terciles than in the moist tercile. This indicates that Hortonian flow (runoff while the soil is partially dry) is important in the study environment. We attribute this flow to a combination of water repellence of the topsoil, and low detention storage on the steep slopes. Catchments to which superphosphate was applied had nearly double the concentration of P in runoff water.

Key Words

Hill-slope hydrology, Hortonian flow, infiltration-excess runoff.

Introduction

Extensive pastures on hills grazed by sheep form a large proportion of the catchments of rivers in south-eastern Australia. Management of these hill areas can have a large influence on stream water quality and quantity. Paddock-scale catchment studies in the winter-dominant rainfall zone have shown that application of phosphorus (P) fertiliser increases the P concentration of runoff water, but has little impact on runoff quantity (Ridley *et al.* 2003; Melland *et al.* 2008). In these studies, nearly all runoff occurred in the winter-spring period after the soil profile had filled. This is a time of year when there is generally good ground cover. Most of these studies were conducted on low to moderate slopes (<5%). There remains a need to understand the runoff mechanisms and consequences of fertiliser application on steeper areas. To test whether the timing of flow and impact of fertiliser also applied to steep hills, a study was initiated in the upper Hopkins basin near Ararat in western Victoria. This paper reports a 4-year study of runoff quantity and quality from a series of small catchments in the upper Hopkins basin.

Methods

Catchments

Four small catchments and two larger ones were selected on a sheep grazing property within a steep hill landscape near Ararat in western Victoria. All 4 small catchments were selected to be as similar as possible in aspect and slope, but varied in their stocking rate and fertiliser rate (Table 1). Catchments B-D were adjacent and about 1km from Catchment A. Catchment D drained into Catchment E, and Catchment A into Catchment F. Catchments C and D received 40 kg/ha of P as superphosphate applied once early in the trial (June 2004).

Table 1. Grazing management, size, elevation and orientation of the 6 study catchments.

Catchment	Stocking rate (sheep/ha)	Fertiliser rates (kg P/ha)	Catchment area (ha)	Bottom elevation (m)	Top elevation (m)	Mean slope (%)	Orientation	Drainage line
A	2.5	0	1.2	426	481	33	ENE	Well defined
B	4.4	0	0.9	397	442	29	ESE	Poorly defined
C	4.4	40	1.6	395	446	24	ESE	Intermediate
D	5.3	40	1.7	395	451	27	S	Well defined
E	4.5	~20	8.1	376	380	20	SSE	Intermediate
F	~4	~10	258	347	446	9	SSE	Well defined

According to the Australian Soil Classification (Isbell 1996), the soil is a Bleached-mottled, Magnesic, Yellow Chromosol, and consisted of sandy clay loam topsoil with an organic matter content of 6-16%, overlying a medium clay subsoil. All catchments were vegetated with native and naturalised pastures (mainly *Austrodanthonia* spp, *Themeda triandra, Hypochoeris* spp. *Rumex* spp. and *Trifolium subterraneum*). Vegetation cover exceeded 70% throughout the study, except on Catchment A in autumn 2007 when it declined to 42%. Rainfall was recorded every 15 minutes by an automatic weather station.

Measurements

Polythene and stainless steel flow barriers were installed at the bottom of each of the four small catchments and runoff was directed into stainless steel flumes (Clemmens *et al.* 1984). The height of water flowing through each flume was recorded by capacitance water height recorders and logged every 2-5 minutes. Water height was related to flow by means of a published calibration relationship (Clemmens *et al.* 1984). Below the weir, flow was directed into a stainless steel after-weir from which samples were collected by an automated water sampler, activated every 30 minutes when water was detected (ISCO 3700 sampler and 1640 liquid level actuators, Teledyne ISCO, Lincoln, Nebraska, USA). As a backup to the automatic samplers, 6 rising stage samplers were installed at 10 mm increments above the level at which water flowed over the flume. Catchment E was monitored hourly at a farm dam by a pressure-sensitive recorder. A topographic survey of the dam was used to convert water height into storage volume. Catchment F (the Hopkins River) was monitored by a V-notch weir installed within a gully control structure. Water heights were converted into flow using a published calibration relationship (Grant and Dawson 2001). Water quality samples were not collected from catchments E and F. Water samples were digested in potassium persulfate (Clesceri *et al.* 1998; method 4500-P B) followed by total P determination by auto analyser at 882 nm using ascorbic acid as the reductant (Clesceri *et al.* 1998; method 4500-P E). To measure total nitrogen, NO_3^- in the digested samples was reduced to NO_2^- in a copperized Cd column, and the NO_2^- was determined by auto analyser at 520 nm (Clesceri *et al.* 1998; method 4500-NO_3^- E). The concentration of solids was determined by evaporation and weighing (Greenberg *et al.* 1992; methods 2540 B and D).

Soil water

In catchments B, C and D, 4-5 aluminium access tubes were installed 10-30 m upslope of the flow barriers, and soil moisture measurements made using a neutron moisture meter (NMM) at intervals of 4-12 weeks. Reading depths were 150 mm, 300 mm, then at 200 mm intervals to the bottom of the access tube at between 900 and 1500 mm depth. Frequency domain reflectometers (CS615, Campbell Scientific, Inc., Logan, Utah, USA) were installed at a single location close to the weather station and logged hourly. These were placed at depths of 0-100 mm (sloped upwards from the installation pit), 100-200 mm, 400 mm and 800 mm. Soil moisture storage was calculated on a daily basis from reflectometer data for the 0-1m depth range.

Results

Mean annual runoff showed a 100-fold range between catchments from 0.14 mm/yr on Catchment B, to 14.5 mm/yr on Catchment A (Table 2). Some catchments produced runoff even in 2006, which was a year of exceptionally low rainfall. Runoff was greatest on catchments with well defined drainage lines. Rainfall during the study period was well below the long-term average (1900-2006) of 613 mm/yr.

Table 2. Summary of annual rainfall and overland flow (mm/year) from the catchments.

Year	Rainfall (mm/yr)	Catchment A	B	C	D	E	F
		Overland flow (mm/year)					
2003*	416	8.2	0.00	0.37	10.10	1.81	5.5
2004	427	21.8	0.42	0.37	5.75	4.06	1.2
2005	605	24.8	0.26	1.35	6.02	4.27	13.4
2006	368	3.2	0.00	0.00	0.54	0.38	0.02
2007*		13.1	0.01	0.00	3.02	0.49	15.9
Mean 2004-2006	467	14.5	0.14	0.42	5.58	2.63	5.0

* Flow data were only recorded for partial years

Soil moisture followed a general pattern of wetting up during autumn and winter, and drying in spring and early summer, but there were short-term maxima following summer storms (Figure 1). In 2006 the soil did not fill to the same extent as in previous years. Soil moisture recorded by the reflectometers (at a single position) was consistent with that from the NMM reading (13 positions), except for one storm in January

2005. Since the reflectometer dataset, which was available on a daily timestep, was generally consistent with the NMM data, and included the 0-100mm layer (which could not be read by the NMM), it was used to classify overland flow by antecedent soil moisture. These data show that in four of the catchments, more flow occurred in the dry or intermediate tercile than in the moist tercile (Table 3). The P concentration from catchments to which P fertiliser had been added was nearly double those of unfertilized catchments (Table 4). The greatest loads were from Catchment A, which had the greatest total flow.

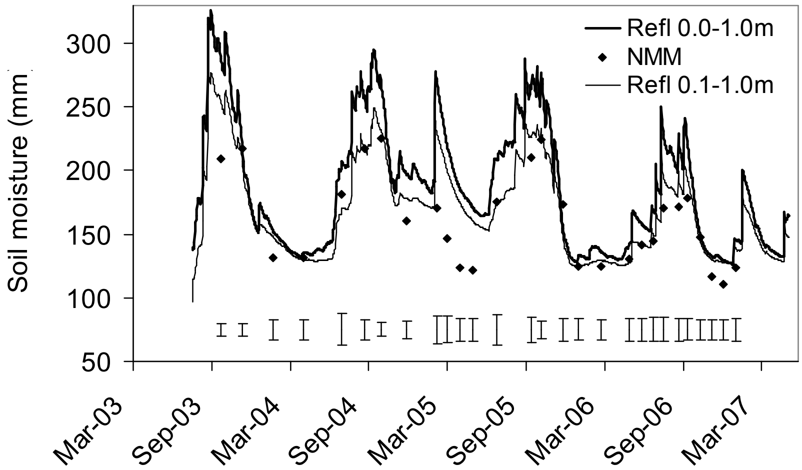

Figure 1. Soil moisture recorded by reflectometers at catchment C (0.0-1.0 m and 0.1-1.0 m), compared to neutron moisture meter (NMM) data averaged across B, C and D catchments (0.1-1.0 m). Error bars are the standard error of the site mean soil moisture for each NMM reading date.

Table 3. Overland flow January 2004 to May 2007, classified according to antecedent soil moisture.

Soil moisture tercile	Catchment					
	A	B	C	D	E	F
	Total overland flow (mm)					
Dry	24.7	0.30	0.34	4.15	1.85	15.9
Intermediate	28.7	0.39	0.08	2.05	4.48	5.88
Moist	9.5	0.0	1.31	9.14	2.89	8.74

Table 4. Flow-weighted concentrations (±standard error) and loads from January 2004 to December 2006.

	Catchment			
	A	B	C	D
	Concentration (mg/L)			
Total P	0.52 (0.13)	0.48	0.96	0.88
Total N	5.03 (0.69)	1.42	3.88	2.97
Suspended solids	50 (12)	33	24	16
Total solids	171 (20)	66	214	141
Total dissolved solids	104 (9)	33	189	107
	Load (kg/ha.yr)[1]			
Total P	0.085	0.001	0.005	0.036
Total N	0.847	0.003	0.022	0.122
Suspended solids	6.39	0.075	0.14	0.66
Total solids	22.9	0.15	1.23	5.80
Total dissolved solids	15.5	0.07	1.08	4.42

[1] Does not include bed load

Discussion

A high proportion of total runoff occurred when the soil was in the dry tercile, whereas in previous studies on gentler slopes, most flow occurred when the soil was moist. This indicates that Hortonian flow (infiltration-excess flow that occurs before the soil fully wets up) is an important flow generation mechanism in our steep hill environment. Other studies of steep areas (1-16% slopes) in uniform rainfall environments in New South Wales have also shown runoff occurring when the soil was still partially dry (Lane *et al.* 1994; Hughes *et al.* 2008). Our landholder noted that during the 2006 drought, some dam-fill occurred on his hill country, but not on the flatter catchments.

In the dry tercile, surface flow was initiated by rainfall intensities as low as 2.6 mm/hr (data not shown). We observed water repellence during light rain on 29 March 2003, when water flowed across the soil surface despite the underlying topsoil being dry. Repellence is common on topsoils such as those in this study that are high in organic matter but low in clay (Ritsema and Dekker 1996). In water-repellent soils, infiltration initially occurs through preferred pathways within the topsoil until the soil wets from below, breaking the repellence of the surface layers (Ritsema and Dekker 1996). Detention storage would therefore be important in the initial wetting of the soil. However, on steep slopes this storage would be limited. We attribute the Hortonian flow to the combination of low detention storage on steep slopes and water repellence of the topsoil when dry.

There was large variation in runoff from the various catchments, with those on defined drainage lines contributing the most runoff. This is consistent with Barling *et al.* (1994) and Melland *et al.* (2008), who reported that surface runoff was preferentially generated from areas of convergent topography. These convergent areas are clearly preferable as catchments for farm dams. Catchments to which superphosphate was applied had nearly double the concentration of P in runoff water. This is also consistent with other studies where similar rates of P were applied (Ridley *et al.* 2003; Melland *et al.* 2008). In the environment of this study, fertiliser did not generate sufficient additional pasture growth to justify the cost (data not shown), and is not a necessary part of hill country management other than replacing the P removed by grazing livestock.

Acknowledgements

We thank the Glenelg-Hopkins Catchment Management Authority for funding this study through the National Action Plan for Salinity and Water Quality. We also thank Robert, Debbie, and Kerry Shea for allowing access to their land for the study. Sheldon Johnson, Tim Jackson, Jerry Chin and Alan Byron provided technical assistance during the project.

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Sediment control practices in sloping highland fields in Korea

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Abstract

Soil erosion and muddy runoff from sloping highland agricultural fields located at the uppermost of major river systems in Korea have caused serious water quality problems in providing domestic water supply and maintaining the river ecosystem. The government designated the upper Soyang Watershed as a priority non-point source(NPS) pollution management region in the middle of 2007 and began to introduce various best management practices (BMPs) extensively to reduce soil erosion, muddy runoff and other NPS pollution discharges. Soil, crop, agricultural management practices and rainfall characteristics of the watershed were explained. Typical BMPs introduced were vegetated filter strip (VFS), vegetated levee, concrete drain channel, concrete diversion, gabion wall, masonry wall, drop structure, slope stabilization, sediment trap, perennial crop, and furrow dam. The functions of these BMPs were explained and recommendations were made for better implementation in the future. Most of the BMPs were not targeted for source control and the necessities for source control were emphasized. It was recommended that the Ministry of Environment (MOE) and the Ministry of Food, Agriculture, Forest and Fishery (MOFAFF) cooperate in controlling and managing agricultural NPS pollution, reducing the possibility of implementing wrong policies and programs, and helping improve water quality effectively and economically.

Key Words

Muddy runoff, sediment control, highland field, BMPs, soil erosion, water quality

Introduction

Land reclamation of steep mountain forests in the uppermost alpine watershed of the Han River in the 1980s to supply fresh vegetables has caused serious water quality problems due to muddy runoff. Muddy runoff from sloping highland fields during the monsoon season increased turbidity seriously as well as total nitrogen and total phosphorus concentrations in downstream water bodies. The impact of water quality degradation is very influential because the river is the one and only water source for Seoul metropolitan area of about 23 million residents in Korea. Also, the increased turbidity proved to cause serious impacts on the river ecosystem (Kim and Jung 2007).

The soil texture of the highland is mostly sand and/or sandy loam that is very vulnerable to water erosion, resulting in thick muddy runoff during heavy rainfall events. Muddy runoff is not directly drained to the sea but rather stored in a cascade of man-made dam reservoirs along the river and slowly discharged and creates the turbidity problem for a prolonged period. Especially in 2006 and 2007, the duration of muddy runoff in the North Han River lasted more than 240 days and caused serious disturbances in water supply and river ecosystem. The Korean government has not been very enthusiastic in controlling the muddy runoff until the turbid flow created serious public attention and awareness of soil erosion. Due to the event, the government declared the area (Soyang Watershed) as a priority NPS management region in 2007 and began to invest the government budget to reduce muddy runoff and soil erosion. It is the first government initiative in terms of NPS pollution control and management. Soyang Reservoir is the largest man-made lake in Korea and plays a key role in controlling flood and drought and providing domestic water supply in downstream Seoul metropolitan areas. The objective of the initiative was to keep the turbidity at the Soyang Dam site at 50 NTU or less.

Best management practices (BMPs) and technologies to control soil erosion and sediment discharges from highland alpine regions have not been investigated well, either theoretically or experimentally, in Korea. However, because of the prolonged muddy runoff event, the government began to build structural BMPs to reduce muddy runoff from 2008 and monitor the effects of the BMPs from the middle of 2009. The objectives of this paper were to introduce and describe the effectiveness of the BMPs and to suggest recommendations for better implementation of the BMPs in the sloping highland agricultural fields.

Characteristics of Sloping Highland Fields in Soyang Dam Watershed

The area of Soyang Watershed is 269,435 ha, with 85.14% as mountain forest and 4.7% as upland fields (7,313) ha in 2006. Other land uses were urbanized 0.8%, paddy and other agricultural 2%, grassed 0.6%, lake and river 2.2%, and others 6.5%. During the 2006-07 muddy runoff event, total sediment yield from the watershed was estimated at 3,559,961 tons. Landslides in mountain areas, stream bank erosion, and upland erosion during the deluge caused by a heavy rainfall event were major sources of the sediment yield. Among the sediment, 865,062 ton or 24.3% was estimated to be eroded from upland fields. However, if a deluge is not the cause of numerous landslides and river bank erosion, most of the muddy runoff is generated and discharged from uplands, especially from sloping highland fields.

Upland located 600 m above the mean sea level (MSL) is classified and called highland field and upland between 400 and 600 m semi-highland field in Korea. About 53.7% or 3,925 ha of the upland lay 400 m above MSL. The slope of highland and semi-highland fields is not mild. Field slopes <7% comprises 26.3%, while slopes between 7-15% covers 40.9%, between 15-30% takes up 30.2%, and >30% is 2.8% of the area. Average annual rainfall in the watershed during the past 10 years (1997-2006) was 1,370 mm. Two-thirds of the rainfall generally occurred during the monsoon season of June, July and August.

Agricultural practices in the Korean highland fields are quite intensive. Cereal crops are not preferred, but vegetable crops such as potato, radish and Chinese cabbage are mostly cultivated. The soil surface is either disturbed by conventional tillage and seed bed preparation, leaving no surface cover until the crop canopy develops, or soil is mulched with thin plastic sheets at the time of seed bed preparation. The rainfall season begins before the crops develop full canopy, and serious soil erosion and sediment discharge occur from the fields. Runoff from mulched fields with plastic sheet increases because of limited infiltration and rills and gullies easily develop in downward furrows, resulting in high soil erosion and muddy runoff. In a survey, it was found that both chemical and organic fertilizers were applied to the alpine fields at many times greater than recommended doses. Considering the characteristics of soil, crop, rainfall and management practices in highland fields, relevant and aggressive BMPs should be applied to reduce soil erosion, runoff, and NPS pollution load from the fields.

BMPs and Recommendations

Water quality problems caused by muddy runoff from sloping alpine fields have become evident from late 1990s. Central and local governments have begun to apply BMPs to alleviate the negative impact of muddy runoff from fields (Table 1). It is noted that the budget increased sharply from 2008 after the area was designated as a priority NPS pollution management region in the mid-2007.

Table 1. Annual investment and BMPs to reduce muddy runoff from the priority NPS pollution management region.

Budget and BMPs	2001-5	2006	2007	2008	2009	Total
Budget ($\times 10^3$ US$)†	6,212	3,166	3,260	7,005	13,993	33,635
VFS (m^2)	14,391	0	0	0	5,500	19,891
Vegetated levee (m)	8,305	0	0	0	15,775	24,080
Concrete drain channel (m)	15,986	5,431	1,463	16,027	63,510	102,417
Concrete diversion (m)	22,186	12,068	16,472	24,231	53,007	127,964
Gabion wall (ea)	234	376	167	1,906	5,040	7,723
Masonry wall (m^2)	10,879	1,874	2,802	18,998	23,724	58,277
Drop structure (ea)	59	26	86	253	106	530
Slope stabilization (m^2)	98,313	47,294	24,190	61,804	124,700	356,301
Sediment trap (ea)	12	3	1	7	4	27
Perennial crop (m^2)	0	0	0	120,000	0	120,000

†Exchange rate is 1,300 Korean Won, to 1 US dollar.

A vegetated levee is a concept similar to the terrace in the USA, but the scale is much smaller than the terrace. The survey showed it was not effective in reducing muddy runoff and it was recommended not to pursue this BMP anymore. Vegetated filter strips (VFS) in the alpine region is very different from ones found in the USA. The width of VFS is at most 1 m, but mostly <0.5 m, because the field sizes were smaller, ranging mostly from 0.5 to 3 ha. It cannot remove nutrients, but contributes to filtering sediment and preventing rills and gullies at the edge of fields. It was recommended that the VFS width be kept at least 1 m wide by persuading farmers with lucrative incentives, because farmers would not give up their land without any reimbursement.

Concrete drains and diversion channels have been the most popular BMPs in the sloping highland fields. Concrete diversion channels were found to be very effective in preventing soil erosion from fields, because it safely diverted runoff from neighbouring forests to drainage channels. Concrete drain channels however were only effective if placed where the slope of channel was steep enough to erode the bottom and the side of ditch. In many cases, concrete channels were constructed where the slope was mild and no channel erosion was expected. It was recommended that concrete drain channels need not be placed where the slope is low, but should be constructed only where channel erosion is expected. It was observed that large amounts of soil were moved into concrete channels during farming operations, such as tilling and seed bed preparation, because there was often no buffer or vegetated filter strip between the concrete channel and the field. If this was the case, the soil and other debris in the concrete channels needed to be removed in a timely manner before the rain comes. Also, some parts of the base of concrete channels were eroded during runoff events and timely maintenance and reinforcement works were necessary before it collapsed.

Gabion (or rock sack) and masonry walls are placed along stream banks and the mountain toe field boundaries. These were very effective in stabilizing stream banks and steep mountain toe slopes. Also, it helped farmers to not encroach on the mountain toe to enlarge their fields. Drop structures were a part of concrete channels, and were used to adjust the slope of the channel. These were considered as BMPs in Korea. Slope stabilization was an effective means of controlling soil erosion and landslides. Vegetation was the most popular method for slope stabilization. It was recommended that the vegetation treatment be well maintained by applying fertilizers regularly, because the soil was mostly sand and vegetation cannot be established well without the nutrient supply. Sediment traps are small concrete structures that have one or two chambers, 4 to 6 m^3 each, that are placed along concrete channels or at the end of a channel where it drains to a stream. It was found that the chambers, however, could not trap fine sediment particles because of the chambers were too small to trap sediments during the turbulent flow of runoff events. The recommendation was to not construct the small sediment traps. Perennial crop cultivation instead of vegetable crop farming was determined to be a very effective BMP for reducing soil erosion and runoff. It was strongly recommended that perennial crop (e.g. apple, grape, ginseng and wild edible greens) cultivation be supported and expanded.

During the BMP survey, it was found that furrow dams made of small permeable sandbags and/or sheaves of straw worked well in reducing soil erosion and muddy runoff by preventing rills and gullies along furrows. Farmers put small sandbags along furrows to slow down runoff velocity and reduce soil erosion. The furrow dams were very effective in preventing rills and gullies at the downstream end of furrows. Some farmers created the idea of cultivated barley or wheat as a barrier instead of sandbags or straw sheaves. This was also recommended as a BMP to be supported aggressively.

Most of the above BMPs are not aimed at reducing soil erosion and muddy runoff at the source. The source control, such as no-till, reduced tillage, or crop residue cover, were already acknowledged as best practices to reduce runoff and erosion. One of the best source control practices was no-till, where the surface was not disturbed by plowing and left covered with crop residues. The residue cover protects the soil surface from raindrop impact, reducing soil erosion, and because the soil pores are not clogged by eroded soil particles, water infiltration was maintained and surface runoff is minimized. Rills and gullies were the main cause of soil erosion in the highland fields, and since residue cover slowed runoff velocity, the rills and gullies did not develop as readily.

In Korea, there are two important reasons for BMPs to not target the source control. The first and the most important reason is that the authority of the control and management of water quality is in the hand of the MOE. And thus, Ministry of Food, Agriculture, Forest and Fishery (MOFAFF) does not pay much attention to policies and programs related to the prevention of soil erosion and water quality. MOE does not know about the agricultural best management practices and does not want to be involved in the agricultural BMPs, because that is the domain of MOFAFF. MOE doesn't want to interfere in MOFAFF's affairs. It is acknowledged that the contribution of point source pollution to the total water pollution is sharply decreased as the legal and systematic control of point source pollution is practiced. While the contribution of NPS pollution is expected to reach about 70% in 2015, and NPS pollution control and management have become key issues for improving water quality, however, because of the authority, good policies and programs to control soil erosion, muddy runoff and other agricultural NPS pollution are not well developed and implemented. The second reason is the lack of support for agricultural BMP research and incentive systems. Incentive systems for farmers to voluntarily use BMPs is a critical factor for the successful adoption of BMPs. Fundamental theories and techniques of BMPs are already developed in many other countries. Studies and field application experiments to adjust these practices to local agricultural environments are needed. However, BMP application experiments have not been well supported by either MOE and MOFAFF.

It is recommended that MOE and MOFAFF cooperate in controlling and managing agricultural NPS pollution. They have to form a joint task force or committee along with professionals and local governments to share information, develop programs and policies, support research programs, educate rural farmers, establish and support local governance system, and campaign various governmental and civil movements for water quality improvement. Cooperation between MOE and MOFAFF would contribute greatly improving water quality effectively and economically.

During the survey of BMPs in the sloping highland fields, it was noticed that officers and engineers of local governments as well as local engineers in construction and consulting firms did not have proper engineering knowledge and information on the theories and applications of BMPs. They didn't want to try to persuade farmers to join and adopt BMPs in their farming because it is costly and required labour, but there is no incentive system to compensate for farmer to adopt BMPs. The government investment will continue until 2014 or until the goal is achieved. And it is expected that source control to reduce soil erosion and muddy runoff will be introduced more aggressively than before by either MOE and/or MOFAFF because structural BMPs have its limit in reducing muddy runoff.

Conclusions

Agricultural NPS pollution is often called runoff pollution, because of its strong dependency on rainfall and runoff events. NPS pollution is largely affected by management practices, crops, soil characteristics, slope and slope length as well as rainfall amount and intensity. Understanding pollutant fate and transport is critical in developing the right policies and managing the correct practices to reduce soil erosion and muddy runoff. This study separated out the BMPs that were truly effective in controlling runoff and erosion from those that did not work. Knowledge of the potential, limitations and factors that affect the efficiency of individual practices is the first necessary piece of NPS pollution management. Being able to combine the knowledge, including that of any interactions between practices, with site-specific conditions, is the second necessary piece to develop overall system of in-field and off-site policies and practices (Baker *et al.* 2008). Due to these facts, it was recommended to develop programs that educate local government and consulting firm engineers on the BMP theories and application technologies.

Acknowledgements

This research is supported by Han River Environment Research Center, Ministry of Environment, Korea. Also, a part of the paper was supported by the Agricultural and Life Sciences Research Institute, Kangwon National University. We acknowledge the generous support.

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Soil carbon reservoirs at high grassland ecosystems in the Andean plateau of Apolobamba (Bolivia)

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Abstract

High grassland ecosystems are presented in the National Apolobamba Integrated Management Area (ANMIN-A) of Bolivia. This area is the natural habitat of camelid populations, such as vicuna (*Vicugna vicugna*), which is recognized as an endangered species. On the other hand, there is no much information related to soil carbon reservoirs in these ecosystems. The objectives of this study were to: (i) provide information about C stocks in high grasslands in the Andean plateau and (ii) determine the quantity and quality of these C reservoirs. These goals were achieved through the analyses of physico-chemical soil properties using different techniques like ^{13}C CP/ MAS- NMR spectroscopy. Results showed that Wakampata and Puyo-Puyo zones could be excellent carbon reservoirs. Taking into account the total organic matter, there seems to be a good relation between the quality and the quantity of soil organic matter (SOM). Overall NMR spectra pointed out that the degradation of SOM is higher in the Ucha-Ucha, Ulla-Ulla and Caballchiñuni than the other studied areas. Therefore, it is necessary to carry out some soil protection actions in these studied zones in order to improve the sustainable vicuna management and preserve high grassland biodiversity in Apolobamba.

Keywords

Vicuna, *puna*, soil organic matter, ^{13}C CP/ MAS- NMR spectroscopy, biodiversity, degradation processes.

Introduction

Global carbon cycle, mainly, depends on the Soil Organic Matter (SOM) dynamic and The Kyoto Protocol includes the soil C reserves in the grasslands for the reduction of greenhouse effects (Kenneth *et al.* 2007). However, there are no many studies related to C stocks in high grasslands. In many cases, ecosystems in the *puna* or grasslands in the Andean plateaus are degraded as a consequence of anthropogenic activities (Rocha and Saenz 2003), in addition to excessive cattle grazing. Vicuna is an endangered species recognized by The World Conservation Union (IUCN 1996) and its management in the Apolobamba area is an example of sustainable management in indigenous communities. The objectives of this study were to: (i) provide information related to C stocks in grasslands in the high plateaus and (ii) determine the quantity and quality of these C reservoirs.

^{13}C CP/ MAS- NMR spectroscopy technique is used to determine the distribution of some C forms in the SOM. It allows to obtain information without the destruction of C components or the physic-chemical separation (Preston 1996), through the study of chemical region in order to characterize SOM quality and composition.

Materials and methods

The study area, Apolobamba, is located in the northwest of La Paz, in Bolivia. The research was carried out in the *puna* of Apolobamba, the zone with the highest altitude range and also the vicuna habitat. The study area is characterized by udic and frigid soil moisture and temperature regimes (USDA 2006) with an annual average temperature of 4.5 ºC and total precipitation of 505 mm (SERNAP 2006). Vicuna population density was the main reason to select studied zones both alpaca (*Lama pacos*) densities, vegetation species, geo-morphological, and hydrological landscape elements. Eight zones or census places, separated areas with geographic barriers, with different vicuna and alpaca densities were selected: Ulla-Ulla and Killu (low vicuna density, 2.1-9.4 animal/km^2), Ucha-Ucha and Wakampata (medium vicuna density, 9.4-16.5 animal/km^2), Sucondori and Caballchiñuni (high vicuna density, 16.5-23.1 animal/km^2) and Puyo-Puyo and Japu (very high vicuna density, 23.1-58.1 animal/km^2).

A representative soil profile was taken in each census location and three replicate plots of 5 x 5 m were selected. Three replicates, surface and subsurface soil samples, were collected per plot: 0-5 cm and 5-15 cm. Total Organic Carbon (TOC) in the soil was measured using TOC Analyzer (Shimadzu 5000, Japan); both Total Nitrogen (TN) according to Duchafour`s (1970) method. Water Soluble Organic Carbon (WSOC) was determined using TOC Analyzer following Herbert *et al.* (1993) methodology with some variations: samples were shaken two hours and centrifuged 25 min at 4500 rpm and ^{13}C CP/MAS-NMR technique (Varian Unity 300 spectrometer, Germany) was applied in the surface samples of one plot per zone. We divided the spectrum in four functional groups (Faz *et al.* 2002; Kögel-Knabner 2000): alkyl (0-50 ppm), O-alkyl (50-112 ppm), aromatic (112-163 ppm), and carboxyl (163-190 ppm).

ANOVA model was applied to identify significant differences between zones and Tukey´s Test was used to establish homogenous groups. Residue normality was studied by Shapiro-Wilk´s Test and Normal Probability Plot and Bartlett Test´s confirmed the homegenity of the variance.

Results and discussion

Soils studied were clasified into Entisols group (suborder Psamments, Orthents and Aquents) and Mollisols, suborder Udolls, (USDA 2006) and Regosols (suborder Arenic, Haplic and Gleyc) and Phaeozems, suborder Haplic, (FAO-ISRIC-ISSS 2006). Exchange capacity exhibited medium values with the exception of Wakampata and Killu, with high mean values over 20 cmol$_+$/kg in surface samples (Muñoz and Faz 2009). The soils were strongly acid and extremely acids in KCl (Soils Survey Division Staff 1993).

Table 1 exhibits TOC and WSOC mean contents and standard errors and C/N ratio. Wakampata and Puyo-Puyo presented the highest mean TOC content (91.7±5.6 and 72.7±3.8 kg/m^2, respectively) in surface (0-5 cm) and a statistically significant difference was found with other zones. In the contrary, Sucondori exhibited lowest mean TOC value (37.3±2.0 g/kg), both Ulla-Ulla, Caballchiñuni (45.9±2.3 g/kg) and Ulla-Ulla (51.5±6.4 g/kg), respectively) and subsurface samples results exhibited similar TOC contents (Table 1). These zones could receive more MOS as a consequence of the higher *Pycnophyllum* grassland plant covert (Muñoz and Faz 2009). However, all studied zones showed medium C/N values with the exception of Puyo-Puyo (14.3±0.9), where humification processes could be a bit more intense.

According to WSOC results (Table 1), Japu is the zone with the highest WSOC mean value (671.1±129.5 mg/kg); on the contrary, Ulla-Ulla exhibited the lowest WSOC content (249.2±46.4 mg/kg). Wakampata, Puyo-Puyo and Japu surface samples showed WSOC concentrations within the average described by Halvorson and Gonzalez (2008) in grasslands, while all subsurface WSOC contents were above in Apolobamba studied zones. According to Zhao *et al.* (2008) there is a positive relation between WSOC fraction and mineralization processes. Therefore, the mineralization processes could be more intensive in 5-15 cm, especially in Japu, as C/N ratio showed (Table 1).

Table 1. TOC and C/N mean contents and standard errors in surface (0-5 cm) and subsurface samples (5-15 cm) (n=9); WSOC in surface and subsurface samples (n=3).

Zones	Surface			Subsurface		
	TOC (g/kg)	C/N	WSOC (mg/kg)	TOC (g/kg)	C/N	WSOC (mg/kg)
Ulla-Ulla	51.5±6.4 cd	11.9±0.6 ab	249.2±46.4 d	44.5±4.0 abc	13.6±0.9 a	223.8±27.2 d
Killu	58.9±5.2 bc	11.7±0.8 b	456.6±120.3 bc	47.8±2.0 abc	10.0±0.2 c	501.6±17.4 ab
Ucha-Ucha	55.0±3.1 bc	12.2±0.5 ab	353.5±26.8 c	38.8±2.2 cd	11.4±0.6 abc	300.2±1.8 c
Wakampata	91.7±5.6 a	12.7±0.2 a	586.6±141.7 ab	56.2±2.0 ab	10.6±0.1 bc	443.5±27.5 bc
Sucondori	37.3±2.0 d	11.7±0.2 b	269.2±32.5 cd	30.0±2.1 d	12.3±0.6 ab	241.9±14.3 d
Caballchiñuni	45.9±2.3 cd	11.9±0.4 ab	317.8±73.5 c	57.3±2.7 a	13.1±0.7 a	435.1±26.9 bc
Puyo-Puyo	72.7±3.8 ab	14.3±0.9 a	549.5±132.7 ab	50.4±2.6 abc	13.1±0.3 a	381.8±33.8 c
Japu	61.1±5.9 bc	11.3±0.2 b	671.1±129.5 a	43.9±4.0 bc	11.3±0.2 abc	579.7±34.1 a

Taking into account the percentages of carbon functional groups (Figure 1), Wakampata or Japu have more carbohydrates contents considering the higher O-alkyl-C mean percentage, 44±1% and 45±1% respectively, in both zones (Figure 1). As a consequence, the microbiological action could degrade much easier the SOM through humification processes in these zones. On the contrary, Ucha-Ucha, Ulla-Ulla and Caballchiñuni presented lowest mean O-alkyl-C percentages (35±1, 40±0%, 40±0%, respectively). Figure 1 exhibits a relative homogeneity in the aromatic compound distribution, which increased slightly in Japu and Ulla-Ulla (13±1%). These may be zones where degradation processes would develop slightly. A higher lignin concentration in Japu could explain the lower decomposition processes speed in comparison to other zones.

This lignin could come mainly from the native vegetation where *Stipa sp.* was identified (Muñoz and Faz 2009). The fact that the higher carboxyl-C percentages found in Ulla-Ulla and Caballchiñuni (11±1 and 11±0%, respectively) reveals that SOM oxidation degree is higher in these areas, which might lead to certain soil degradation in these census places (Kiem *et al.* 2000) probably due to camelid cattle overexploitation. According to aromatic and carboxyl percentages, the SOM mineralization speed could be faster in Ulla-Ulla and Caballchiñuni with lower SOM stabilization.

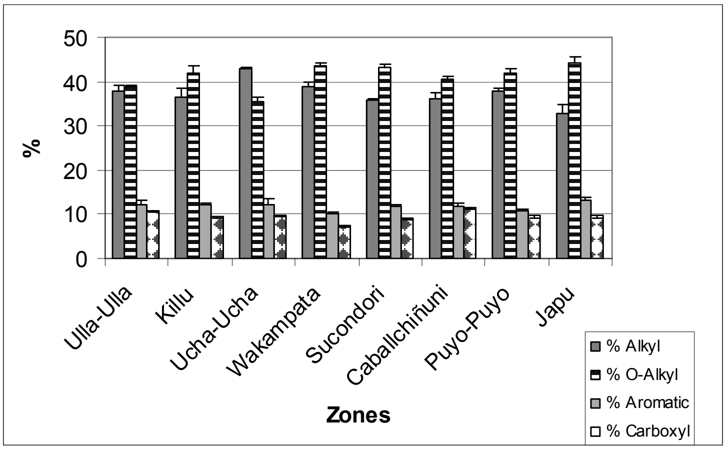

Figure 1. Percentages of ^{13}C-NMR functional groups of the surface soil (0-5 cm; n=3)

Conclusions

In conclusion, some studied zones located in high grasslands in the Andean plateau in Bolivia such as Wakampata and Puyo-Puyo could be an excellent carbon reservoir regarding TOC contents and mineralization processes. In addition, humification and mineralization processes are equilibrated, according to C/N relation.

A good quality and quantity of SOM was found in the studied soils although they are prone to degradation. Thus, it is necessary to carry out some soil protection actions in the studied zones, especially in Ulla-Ulla and Ucha-Ucha, in order to improve the sustainable vicuna management and preserve high grassland ecosystems and their biodiversity in Apolobamba.

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Soil erosion assessment and monitoring by using ImpelERO model in east Azerbaijan province, Iran.

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Abstract

Soil erosion continues to be a major concern for the development of sustainable agricultural management systems. Neural networks, as an artificial intelligence technology, have grown rapidly over the past few years and have an ability to deal with nonlinear multivariate systems. An integrated Model to Predict European Land use named ImpelERO is a decision trees/neural network hybrid model. This paper focuses on the possibility of model application in an area of west Asia by recalibration and generalization. The overall approach of ImpelERO model was applied in 14 natural regions from the east Azerbaijan province, Iran. Results showed that vulnerability indexes vary from 0.03 to 1.32 while risk classes will be very small (V1), small (V2), moderate (V3), large (V4), and very large (V5) in an area extension of 1080, 1860, 1184, 2981, and 1772 hectares, respectively. Lands belong to Zargar and Dizanlou natural regions because of topographical limitation factors are established with a very large risk class. Long term productivity reduction for time horizons 2020, 2050 and 2100 indicutes that management planning is necessary to minimize soil loss rate.

Key Words

Decision trees, ImpelERO model, neural network, soil erosion, West Asia

Introduction

In the last years, scientists working with a new approach in agricultural production: farming by soil, precision agriculture, plot specific management or soil tillage research, have provided new research information on pertinent processes related to soil tillage in order to prevent and reduce soil erosion (Robert *et al.* 1993; Horn *et al.* 1998). Recently, connections have emerged between the neural network technique and its application in engineering, agriculture, and environmental science. Hybrid systems are the combination of dynamic simulation models and empirically based land evaluation techniques. Within the new MicroLEIS DSS framework, the Agricultural Soil Erosion Evaluation Model (ImpelERO) is a decision trees/neural network hybrid model developed to predict the water erosion vulnerability, productivity reduction and optimal management strategies for an agricultural parcel. For evaluating the soil erosion process, formulation, calibration, sensitivity and validation analysis of model were carried out in a total of 237 field-units, which represent 34 major land resource areas for five traditional crops in the Andalusia region, Spain (De la Rosa *et al.* 1999). According to previous reports, soil erosion is an increasing phenomenon not only in Europe (Blum 1990) but also in west Asia (Shahbazi *et al.* 2009a). Therefore, it is necessary to separate the current status from the future risk or soil vulnerability. This paper illustrates assessment of soil erosion vulnerability using the recently proposed approach for predicting agricultural soil erosion to investigate the effects of soil loss on crop yield in semi-arid region which is located in Iran (Shahbazi 2008).

Methods

Western European sites

Mediterranean, Atlantic and Continental regions corresponding to 20 selected benchmark sites in Europe were selected to apply ImpelERO model with Luvisols and Vertisols in the Mediterranean, Cambisols in Atlantic and all soil groups in Continental regions. Dataset files on climate data for meteorological station closer to the selected benchmark sites were compiled from the world weather datdbase (WDA 1994).On the basis of the expert system/neural network structure of ImpelERO model within the new MicroLEIS DSS framework, a computerized procedure was followed to find an appropriate combination of management practices to minimize soil loss for a particular site (De la Rosa *et al.* 2000). According to model generalization option, it can be specifically generalized for each study area while the main goal of this research is to show the possibility of model application outside of the calibrated area such as a semi-arid region.

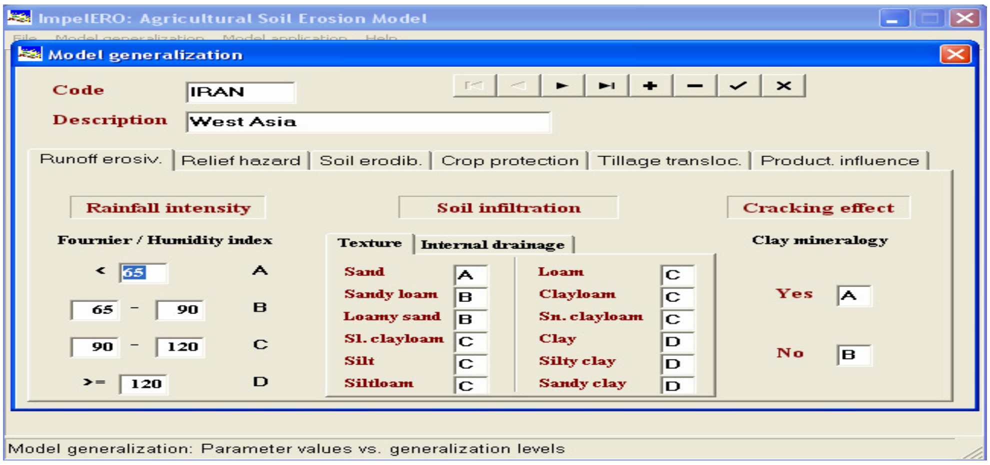
West Asia studied site

The study area covers 14 natural regions and includes 23 soil families within three soil orders: Entisols, Inceptisols and Alfisols in the north-west of Iran, east Azerbaijan province, in an area extension about 9000ha. Typic Calcixerepts are the most dominant subgroups (Figure 1). However, 44 soil mapping units were distinguished according to geo-pedology soil surveying (Shahbazi *et al.* 2009b). Altitude varies from 1300 to 1600m with a mean of about 1450m, and slope gradients vary from flat to more than 10%. The dominant farming system on the studied area is direct seeding on permanent soil cover in wheat- alfalfa-barley rotation. For this case study, the selected benchmark soil physical, chemical and morphological data were stored in SDBm plus which is a geo-referenced soil attribute database and engine of MicroLEIS DSS. On the other hand, the climate database CDBm and farming database MDBm are used as important software to warehouse the basic information.

Figure 1. Site and soil profile described in the studied area (e.g. Clayey, mixed, mesic, semiactive Typic Calcixerepts with soil horizons A, B1, Bk2, C of a dark greyish brown colour on topsoil); Location: 38° 24′31″N and 47° 00′ 58″ E.

Model application and calibration

Basic elements for running the model are region, field unit, soil, climate, management and perturbation. The evaluation region is a complete set of field-units identify the spatial unit of analysis to be evaluated by application of the ImpelERO model. land characteristics is a simple attribute of the land that can be directly measured or estimated in routine natural resource survey referred to the soil which define a field-unit. Land quality will be described following the land characteristics related not only to soil but also to climate characteristics. A set of management characteristics which consider basically crop properties and cultivation practices. It is a simple attribute of the agricultural management that can be estimated and can be employed as a means of describing management qualities. Climate changes referred to temperature and precipitation from the existing meteorological data, and generally based on predictions for future scenario (Christensen *et al*. 2007) were perturbation procedure. There are three main options: i) to enter or edit input data; ii) To create the model generalization calibration is possible. Runoff erosivity, relief hazard, soil erodibility, crop production, tillage translocation and production influence are principal revised parameters according to the nature of tested area and local environmental conditions, only the ratio Fournier/humidity index was revised (Figure 2); iii) to run the model. Testing analysis is under instruction compared to same investigations using USLE and PSIAC methods.



Code: IRAN

Description: West Asia

Fournier / Humidity index

<	65		A
65	–	90	B
90	–	120	C
>=	120		D

Sand	A	Loam	C
Sandy loam	B	Clayloam	C
Loamy sand	B	Sn. clayloam	C
Sl. clayloam	C	Clay	D
Silt	C	Silty clay	D
Siltloam	C	Sandy clay	D

Clay mineralogy

Yes A

No B

Model generalization: Parameter values vs. generalization levels

Figure 2. Generalization levels of each land/management characteristic considered for the studied area.

Spatialization analysis

The spatialization analysis includes the utilization of spatial techniques to expand land evaluation results from local scale to geographic areas using soil survey and other related maps. The use of geographical information system leads to the rapid generation of thematic maps and areas estimates, and enables the use of many analytical and visualization procedures to produce interpreted maps.

Results

The agro-ecological land evaluation decision support system such as MicroLEIS reflects the many advances in these technologies and their possibilities for the development and application to soil quality assessment. Vulnerability index, risk class, soil loss rate (Mg/ha/y) and soil depth reduction (cm/y) are the main outputs from the ImpelERO model which are summarized in Table 1. Areas with a high risk vulnerability (classes V4 and V5 a total of 4753ha) were considered as marginal lands management plan is needed to decrease soil loss rate

Table 1. Summary of model application results in the studied area.

Soil unit	Natural region	Area Ext. (ha)	Risk class	Soil loss rate (Mg/ha/y)	Soil depth reduction (cm/y)	Productivity reduction (%)		
						2020	2050	2100
1	Kord Ahmad	165	V2	7.3	0.06	0	1	4
2	Kord Ahmad	354	V2	8.5	0.07	0	1	5
3	Central Ahar	82	V3	45.2	0.29	2	11	25
4	Central Ahar	93	V1	3.3	0.02	0	0	0
5	Dizaj Chalou	277.3	V4	69.2	0.53	1	5	10
6	Dizaj Chalou	141.7	V5	101.8	0.76	8	29	64
7	Kord Ahmad	64.5	V2	6.2	0.05	0	0	1
8	Central Ahar	84	V3	46	0.41	1	3	8
9	Central Ahar	214	V2	8.7	0.06	0	0	1
10	Central Ahar	89	V2	9.9	0.09	1	3	7
11	Central Ahar	198.1	V2	7.1	0.05	0	1	4
12	Kord Ahmad	55.1	V3	10.7	0.08	0	3	6
13	Dizbin	340	V4	56.9	0.39	4	15	33
14	Dizbin	200	V4	87.3	0.68	7	26	57
15	Mardehkatan	310.5	V5	101.8	0.8	8	31	68
16	Garangah	176	V4	56.9	0.41	1	3	8
17	Garangah	262	V1	4.8	0.03	0	1	3
18	Dizbin	276.1	V5	101.8	0.8	8	31	68
19	Dehestan	220	V4	72.1	0.54	5	21	47
20	Dizaj Talkhaj	264	V5	118.9	0.89	9	36	78
21	Garangah	324.4	V5	117.6	0.97	10	37	82
22	Garangah	180	V4	84.5	0.66	6	25	55
23	Khonyagh	283.3	V2	9.8	0.08	0	0	1
24	Dizbin	130.3	V2	6	0.04	0	1	3
25	Dehestan	282	V4	70.6	0.53	1	5	10
26	Mardehkatan	165	V2	9.9	0.07	0	3	6
27	Garangah	246	V3	45.2	0.28	3	10	23
28	Garangah	22.4	V4	74.4	0.55	6	21	46
29	Khonyagh	167	V1	3.1	0.03	0	0	0
30	kalhor	298	V1	4.9	0.03	0	1	3
31	Dizaj Talkhaj	128.7	V3	12.6	0.08	0	3	6
32	Mardehkatan	183.3	V4	88.8	0.79	2	7	15
33	Garangah	328	V3	45.2	0.28	0	2	5
34	Cheshmevazan	180	V2	9.9	0.07	0	0	1
35	kalhor	30	V4	4.8	0.57	1	5	11
36	Dehestan	490	V4	70.6	0.54	1	5	10
37	Kordlar	140	V2	9.9	0.08	0	3	6
38	Kordlar	261	V1	4.8	0.03	0	1	3
39	Garangah	367	V4	70.6	0.51	6	19	43
40	Gorchi	213	V4	88.8	0.74	1	6	15
41	Kalhor	134.1	V3	46	0.34	1	3	6
42	Kordlar	237.3	V5	101.8	0.83	8	31	70
43	Dehestan	110	V3	23.2	0.17	2	6	15
44	Zargar	218	V5	145.2	1.32	14	51	100

Conclusion

According to the obtained results, productivity reduction due to soil loss rate and soil depth reduction in 20 examined soil mapping units is appreciable. Decreased soil erosion is the basic principal of sustainable agricultural practice focusing on the positive effects on the soil quality. A vulnerability classification map can be provided by integrating the model results with GIS (Figure 3).

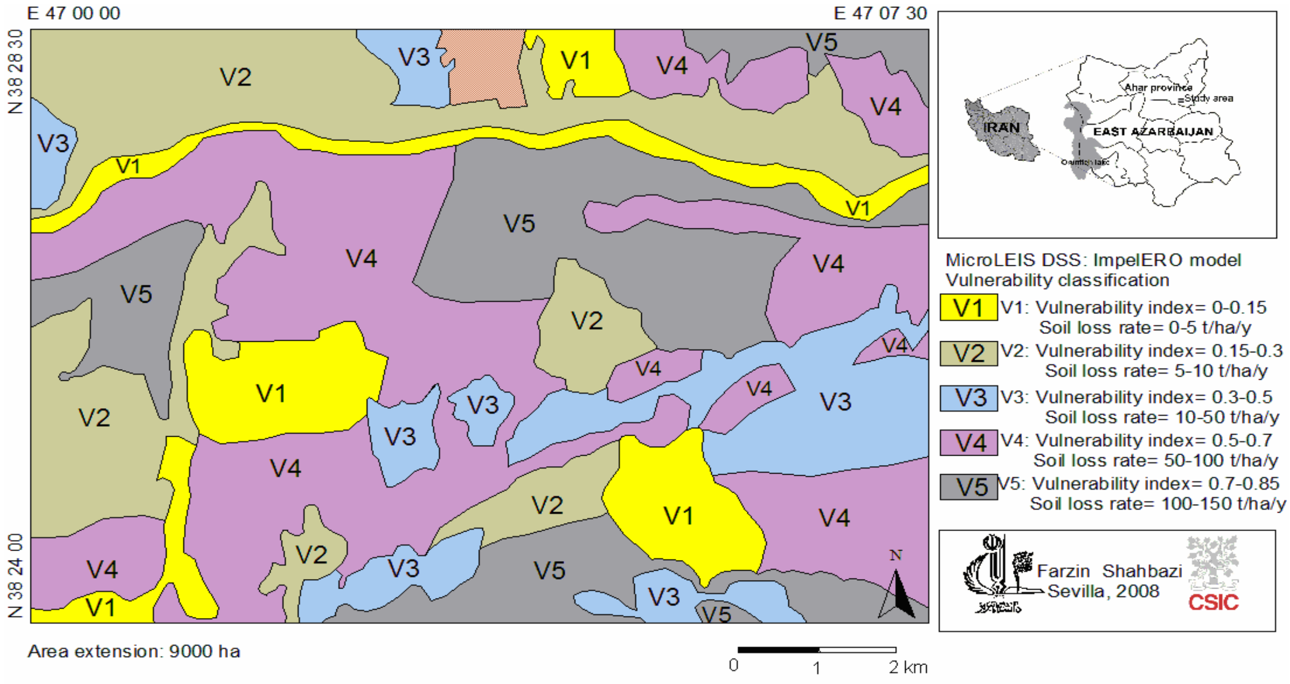


Figure 3. Vulnerability classification map of studied area.

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Soil fertility management options in sweet potato based cropping systems in the highlands of Papua New Guinea

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Abstract

The highlands of Papua New Guinea have one of the highest rates of population growth amongst developing nations, yet the area under agricultural production has not increased accordingly, leading to land use intensification and concomitant soil productivity decline as length of fallow periods decrease. One opportunity to counter soil productivity decline is to extend the use of large composted mounds, or 'Engan' mounds, outside the areas where this method is traditionally practised and has enabled almost continuous Sweet potato based cropping systems. Accordingly, field trials were conducted in 3 highlands provinces to evaluate a range of farmer adoptable soil management practices aimed at combating soil fertility decline. In the first season of these 3-season trials, we observed that large composted mounds containing high value compost materials such was lupines or wild Mexican sunflower, produced substantial yield increases on poorer soils low in N, K and S. The potential of nutrient losses through leaching in these high rainfall areas was also investigated. The results suggested that nitrate losses are negligible as long as compositing material of low nutrient content is used. Hence, the use of organic matter in composted mounds at this stage seems a better soil fertility management option for sweet potato farmers in the highlands of Papua New Guinea.

Key Words

Composted mounding, sweet potato, soil fertility management.

Introduction

Sweet potato based cropping system account for up to 90% of land under cultivation in the Highlands of Papua New Guinea (PNG). Despite very high rates of population growth, the area under agricultural production has remained relatively stable (Bourke 1997, 2001) with concomitant intensification of land use leading primarily to a shortening of fallow periods. Reports on changes in length of fallow periods are variable due to the tremendous variety of land use practises. In some parts of the Highlands, fallow periods may still exceed 20 years, while in others areas, in particular the composting zone of the high altitude areas in the provinces in the west, very little fallowing is done. Overall, length of fallow periods has significantly decreased as the population has expanded. There is now evidence that decreases in soil productivity is impacting Sweet potato yields, the region's main staple food crop. A recent study (Kirchhof *et al.* 2009) has shown that Sweet potato yields decline from around 8 t/ha in gardens that came out of a 2 to 5 year fallow period to 4 t/ha in gardens that were about to go into a fallow period. This decline was linked to inadequate N, K and S nutrition and was more pronounced where small mound tillage was practised. In contrast, soil management practises using Engan (large composted) mounds were the least affected by soil fertility decline. These Engan or large composted mounding systems consist of round or oval mounds, at least 10 m^2 in area and up to 1 m in height (Taraken and Ratsch 2009). Mound productivity is maintained by placing about 30 kg of biomass, cut from the surrounding area, into the inside of the mound before Sweet potato planting. Although these large composted mounds represent an opportunity to minimise soil fertility decline in systems where mineral fertilisers are not used (D'Souza and Bourke 1986; Floyd and Lefroy 1988), they have not been adopted outside their traditional zones in PNG. However, two decades after the work in the 1980s, farmers are now becoming aware of poor Sweet potato yields as a consequence of land use intensification (Kirchhof *et al.* 2009). The objectives of this study were to develop farmer-adoptable soil management practises incorporating compost mounding systems and including different types of fallow vegetation. Results from the first year of field trials are presented in this paper.

Materials and methods

Fields trials were located in Aiyura (Eastern Highlands Province), Kondiu (Simbu Province) and Tambul (Western Highlands Province). Soils were classified as Humult (Aiyura), Aquept (Kondiu) and Aqoll (Tambul). All sites had just come out of a fallow period of at least 2 years. Soil management treatments applied were the same in Aiyura and Kondiu, but different in Tambul where only variants of the large mounding systems were investigated (Table 1). Besides a simple comparison of individual treatments, the trial was designed to allow the evaluation of different management effects such as addition and management of biomass as mulch or compost, tillage and mound size, by grouping treatments with equal sub-management factors. Sweet potato vines were planted following land preparation and harvested 5 months after planting in Aiyura and Kondiu, and 10 months after planting at the high altitude area in Tambul. Direction of water movement was monitored using tensiometers and calculating hydraulic gradients, and potential leaching of nitrate was measured in soil water extracts using Merckoquant colorimetric test strips for 10 to 500 ppm. Final biomass and tuber yields were measured.

Table 1. Treatments (soil preparation/fallow management/crop rotation used at the 3 trial sites.

	Soil preparation	Fallow/biomass management	Crop rotation	Aiyura Kondiu*	Tambul
1	Large mounds	20t/ha grass compost buried in mounds	Sweet potato – fallow – sweet potato	√	√
2	Large mounds	50t/ha grass compost buried in mounds	Sweet potato – fallow – sweet potato		√
3	Large mounds	50t/ha Wild mexican sunflower compost buried in mounds	Sweet potato – fallow – sweet potato		√
4	Large mounds	50t/ha Lupine compost buried in mounds	Sweet potato – fallow – sweet potato		√
5	Large mounds	No compost	Sweet potato – fallow – sweet potato		√
6	Large mounds	Fallow vegetation slashed and burnt – ash enriching the soil	Sweet potato – fallow – sweet potato		√
7	Small mounds	Fallow vegetation slashed and burnt – ash enriching the soil	Sweet potato – fallow – sweet potato	√	
8	Small mounds	Fallow vegetation slashed and burnt, and extra compost added to mounds from surrounding area	Sweet potato – fallow – sweet potato	√	
9	Small mounds	Fallow slashed but not burnt and used a mulch	Sweet potato – fallow – sweet potato	√	
10	Small mounds	Fallow vegetation slashed and burnt – ash enriching the soil	Sweet potato – peanut – sweet potato	√	
11	Small mounds	Fallow vegetation slashed and burnt – ash enriching the soil	Sweet potato – sweet potato – sweet potato	√	
12	Flat beds	Fallow vegetation slashed and burnt – ash enriching the soil	Sweet potato – peanut – fallow – sweet potato	√	√

*Treatments 7, 10 and 11 are identical in the first cropping phase

Results and discussion

Water movement and Nitrate leaching

As expected, due to the high rainfall in the PNG Highlands, hydraulic gradients were mainly positive showing a leaching environment. Average gradients downwards were largest in Tambul, followed by Aiyura and Kondiu. However, despite a net water movement down the profile, leaching of nitrate was only observed at the start of the cropping phase in Tambul. This may indicate that nutrient losses through leaching in a system without mineral fertiliser application are of little importance, except in very high rainfall areas where large amounts of compost or high value compost are added. However, these preliminary finding should not distract from the possibility of nutrient leaching if mineral fertilisers are added to the large mounding systems.

Sweet potato yields

Sweet potato yields at Aiyura ranged from 17 t/ha to 30 t/ha, with Treatment 1, the Engan mounds, having the lowest yield (p=0.052). However, compared to all other treatments, the Engan mounds had no large tubers and significantly more medium and small size tubers (p=0.04). This suggested that the yield potential using Engan mounds had not been realised and that sequential harvesting, as practised by farmers, might improve yield substantially. Statistical analysis of sub-factors (management of biomass as mulch or compost, tillage and mound size) was not significant. The general lack of treatment impact on yield was attributed to the fact that the site had come out of a long 5-year fallow period. The range of yields at the Kondiu site was similar to the Aiyura site (15 to 30 t/ha). However, in contrast to the Aiyura site, Treatment 1 (Engan mounds) out-yielded all other treatments with a yield of 29.9 t/ha (p=0.001). The higher yield was due to more tubers in all size classes compared to the other treatments. There was no tillage effect on tuber yield, but composting, even in small mounds, improved yield compared to the conventional practise of burning. The most striking difference between the Aiyura and Kondiu sites was the yield on Engan mounds. Again we contributed this difference to past land use where Kondiu only had 2 years of fallow and had an overall poorer quality soil, being particularly low in S and exchangeable K. However, yield monitoring for the following years is needed to support the hypothesis that Engan mounds are a suitable alternative to land management outside the traditional mounding zone.

Yields at the Tambul site were tremendously low ranging from below 1 t/ha to 10 t/ha. The relatively poor yields on this site were attributed to the site history. The area is an old lake that and had partly been filled with tephra about 90,000 ago. The lake subsequently dried and formed a swamp. Organic carbon content of the soil now is more then 20% in the topsoils and bulk densities range from 0.22 to 0.37 g/cm^3. The site was drained for grazing about 3 decades ago, but has never been cultivated. In the first year of cultivation and cropping there was insufficient mineralisation, rendering this a very unproductive soil. However, productivity is expected to increase as organic matter mineralises over time. The highest tuber yields of 10.1 and 8.8 t/ha ($p<0.001$) were recorded in the treatments where high value compost, wild Mexican Sunflower (*Tithonia diversifolia*) and Lupines (*Lupinus perennis*), respectively, had been added. This treatment effect supported our assumption that easily mineralisable material needs to be added to this poor soil to get any appreciable amount of tuber yield.

Conclusion

Results from the 1st year of a 3 year study on Sweet potato productivity showed that the large Engan compost mounding systems has the potential to overcome soil productivity decline on soils outside the traditional mounding zone in the Highlands of PNG. Yield improvements at this stage are most pronounced on soils with inherently low soil fertility. Composting, rather than burning could be the first step countering soil fertility decline. Preliminary results also showed that, even though the areas are in a strong leaching environment, nutrient losses were negligible. While at this stage there is little indication that leaching may be a problem in systems where only organic fertilisers are applied, we advise caution in the use of soluble mineral fertiliser.

Acknowledgement

This research is part of a 5-year ACIAR funded project and we wish to thank ACIAR for providing support to attend and present the current results to the World Congress of Soil Science.

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Soil physical attributes induced by crop sequence under no-tillage system in tropical region with warm and dry winter

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Abstract

The no-tillage system is utilized in approximately 100 million hectares in the world. However, this system still needs to be better adapted to tropical regions, with warm and dry winters. The adaptation of no-tillage system in tropical regions depends on the suitable choice of summer and winter crops which should contribute to improvement of soil properties and soil productive capacity. The aim of the present study was to determine the effect of crop sequences on soil physical attributes of a Rhodic Eutrudox under no-tillage system. The treatments consisted of the combination of tree summer crop sequences and seven winter crop sequences. The summer crop sequences were: maize monocrop (Zea mays L.), soybean monocrop (Glycine max (L.) Merrill), and soybean/maize rotation. The winter crops were: maize, sunflower (Helianthus annuus L.), radish (Raphanus sativus L.), pearl millet (Pennisetum americanum (L.) Leeke), pigeon pea (Cajanus cajan (L.) Millsp), grain sorghum (Sorghum bicolor (L.) Moench) and sunn hemp (Crotalaria juncea L.). The experiment began in September 2002. Lower bulk density and high soil tensile strength were found in the soybean/maize rotation after sorghum and sunn hemp. Sorghum and sunn hemp provided the highest water-stability of soil aggregates. Millet, sorghum, maize and sunn hemp provided the highest mean aggregate diameter. The water-stability of soil aggregates and mean aggregate diameter showed positive correlation with soil tensile strength. There were no differences among effects of the summer and winter crops on the soil organic matter. In general, better soil physical conditions were found in the soybean/maize crop rotation and after sunn hemp, sorghum and millet.

Key Words

Soil aggregation, soil structure, winter crops, cover crops, tropical agriculture.

Introduction

In the no-tillage system, the physical management of the soil is in practice limited to the sowing operation and to the effect of the crops on soil structure. The rotation of crops with species that increase plant residues on soil surface is fundamental to avoid soil erosion and to improve soil physical quality. Plants affect soil structure at different scales and through various direct and indirect mechanisms. The adaptation of no-tillage system in tropical regions depends on the suitable choice of summer and winter crops which should contribute to improvement of soil properties and soil productive capacity. To achieve this, the choice of adapted crops to establish the system is of fundamental importance. The aim of the present study was to determine the effect of crop sequences on soil physical attributes of a Rhodic Eutrudox under no-tillage.

Methods

Characterization of the experimental área

The field experiment was established in 2002 at Jaboticabal, SP, Brazil (218140S, 488170W and altitude of 550 m). Climatologically the area belongs to tropical/megathermal zone or Koöppen's Aw (a tropical climate with dry winter and the temperature average of the coldest month higher than 18 8C). The mean annual rainfall (1971–2006) is 1417 mm, with an annual distribution peaking in the period of October–March and a relatively dry season in the period of April–September. The soil of the experimental area is an Oxisol (Rhodic Eutrudox), based on USDA Soil Taxonomy (Soil Survey Staff 2003). In the 0– 20 cm layer, the mean contents of clay, silt and sand were 555, 63 and 381 g/kg, respectively, determined by the pipette method (Gee and Bauder 1986).

Experimental design

The experiment was conducted using a split-block design. Two sets of treatments (tree summer crop sequences and seven winter crops, totaling 21 plots per experimental block) are randomized across each other in strips in an otherwise randomized complete block design, as described by Little and Hills (1975). There were three replications (blocks). Each plot was 40 m long by 15 m wide. The summer crop sequences, with sowing in October/November, were: maize monocrop (Zea mays L.); soybean monocrop (Glycine max (L.) Merrill); soybean/maize rotation. The winter crops, with sowed in February–March and repeated every year in the same plots, were: maize, sunflower (Helianthus annuus L.), oilseed radish (Raphanus sativus L.), pearl millet (Pennisetum americanum (L.) Leeke), pigeon pea (Cajanus cajan (L.) Millsp), grain sorghum (Sorghum bicolor (L.) Moench) and sunn hemp (Crotalaria juncea L.).

Soil sampling and analysis

Soil sampling took place after finishing the six year of the experiment, on October 2008, before sowing the summer crops of the next growing year (2008/2009). Four soil blocks measuring 10x20x15 cm of high, length and width, respectively, were taken from each plot. Then, aggregate (12.5 to 19.0 mm diameter) were taken from the blocks. Forty of these aggregates were used to evaluate soil tensile strength (Dexter and Kroesbergen 2000), 10 more remained to determine bulk density. Other aggregates (4.0 to 6.3 mm diameter) were separated to evaluated mean pondered aggregate diameter (Yoder, 1936), and other ones (1.0 to 2.0 mm diameter) were used to determine water-stability of soil aggregates (Kemper & Rosenau 1986). After evaluating the soil tensile strength, soil samples from aggregates were separated to evaluate soil total organic matter. The results were submitted to variance analysis (F test) and means were compared by the Tukey test ($p < 0.10$). Pearson linear correlation test was applied to evaluate soil attributes that showed significant differences among treatments.

Results

Lower bulk densities were found in the soil after oilseed radish, sorghum and sunn hemp in the soybean/maize rotation and after sunn hemp in the maize monocrop (Table 1). High soil tensile strength was found after sunn hemp in the soybean/maize rotation (Table 2). Sorghum and sunn hemp provided the highest water-stability of soil aggregates, independently of the summer crop sequence (Table 3). Highest mean pondered aggregate diameters were found in the soybean/maize rotation and in maize monocrop, independently of the winter crops (Table 3). Pearl millet and sorghum provided the highest mean pondered aggregate diameter, independently of the summer crop sequence (Table 3). The water-stability of soil aggregates and mean pondered aggregate diameter showed positive correlation with soil tensile strength (Table 4). There were no differences among effects of the summer and winter crops on the soil organic matter (Table 3).

Table 1. Soil bulk density after winter crops in the summer crop sequences.

Winter crops	Summer crop sequences						F test
	Soybean/maize rotation		Maize monocrop		Soybean monocrop		
Maize	1,51	A[a]	1,47	AB	1,45		1,71^{ns}
Sunflower	1,45	ABb	1,53	Aa	1,48	ab	2,90*
Oilseed radish	1,41	B	1,45	AB	1,45		1,84^{ns}
Pearl millet	1,46	AB	1,48	AB	1,46		1,48^{ns}
Pigeon pea	1,43	AB	1,44	AB	1,41		0,35^{ns}
Grain sorghum	1,41	B	1,43	AB	1,44		0,86^{ns}
Sunn hemp	1,40	B	1,40	B	1,44		0,37^{ns}
F test	1,99*		2,75*		0,75^{ns}		

Data followed by same low case letter in line or same high case letter in the column are not considered different by Tukey test at 10% of probability.

Table 2. **Soil tensile strength (kPa) after winter crops in the summer crop sequences.**

Winter crops	Summer crop sequences						F
	soybean/maize rotation		maize monocrop		soybean monocrop		
Maize	47,64	AB[a]	42,58		38,86		1,42 ^{ns}
Sunflower	48,92	ABa	39,59	ab	32,92	b	4,72*
Oilseed radish	39,53	B	42,41		35,53		0,87 ^{ns}
Pearl millet	48,99	AB	44,65		44,93		0,43 ^{ns}
Pigeon pea	38,19	B	35,27		41,40		0,69 ^{ns}
Grain sorghum	46,89	AB	48,18		41,49		0,92 ^{ns}
Sunn hemp	56,84	Aa	37,83	b	34,77	b	10,43*
F test	2,71*		1,28^{ns}		1,28^{ns}		

Data followed by same low case letter in line or same high case letter in the column are not considered different by Tukey test at 10% of probability.

Table 3. Soil Organic matter (OM), water-stability of soil aggregates (WSA), mean pondered aggregate diameter (MPAD) and soil bulk density (BD), determined from soil submitted to the crop sequences.

Summer crops (S)	OM (g/dm^3)	WSA (%)		MPAD (mm)		BD (g/cm^3)
soybean/maize rotation	11,9	74		3,22	a	1,45
maize monocrop	12,2	72		3,17	a	1,46
soybean monocrop	12,2	73		2,76	b	1,45
F test	0,49^{ns}	2,24^{ns}		6,34*		0,28^{ns}
CV(%)	10,7	3,3		15,0		4,1
Winter crops (W)						
Maize	11,7	69	bc^{a}	3,21	ab	1,48
Sunflower	11,8	68	c	2,95	abc	1,49
Oilseed radish	11,9	70	bc	2,65	c	1,45
Pearl millet	12,2	75	ab	3,31	a	1,44
Pigeon pea	12,0	73	abc	2,83	bc	1,42
Grain sorghum	12,3	77	a	3,27	a	1,43
Sunn hemp	12,4	78	a	3,12	ab	1,44
F test	0,46^{ns}	8,40*		7,87*		1,16^{ns}
CV (%)	9,0	5,5		8,6		4,4
Interaction SxW						
F test	0,87^{ns}	0,88^{ns}		1,31^{ns}		1,81*
CV (%)	7,2	3,1		8,0		2,8

Data followed by same low case letter in line not considered different by Tukey test at 10% of probability

Table 4. Coefficient of correlation between bulk density (BD), water-stability of soil aggregates (WSA), and mean pondered aggregate diameter (MPAD) and soil tensile strength.

Independent variables	Dependent variables
	Soil tensile strength
BD	ns
WSA	0,56**
MPAD	0,37**

Pearson correlation coefficient. ** P < 0,01; ns: not significant.

Conclusion

In general, better soil physical conditions were found for the soybean/maize summer crop rotation and after sunn hemp, sorghum and millet winter crops.

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Soil porosity affected by cattle trampling in highland agriculture of Northern Mexico

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Abstract

The impact of agriculture practices on soil porosity is shown for high grassland of the Nazas River (Northern Mexico). The image analysis method applied to a non perturbed soil monoliths let's compares soil porosity between areas of well conserved grassland and areas degraded because of overgrazing and cattle trampling. Results show that soil porosity is reduced up to 32 % in degraded areas characterized by round and vesicular micro-porosity. On the contrary well conserved grassland areas show higher porosity (up to 43 %) dominated by macro pores (bigger than $2mm^2$ with an irregular shape) associated with grass roots abundance. This paper determines the hydrological consequences of studied surfaces in terms of infiltration and run off in the watershed.

Key Words

Soil porosity, image analysis, watershed hydrology

Introduction

Soil surface porosity is important for water infiltration and runoff toward shallow or deep soil levels (Gonzalez-Barrios *et al.* 2008). Flow dynamics in soil are realized into porous media having different sizes, shapes and distributions within soil profile. Soil porosity can be measured with microscopic tools on thin sections (González-Cervantes *et al.* 2004; Maragos *et al.* 2004; Mooney *et al.* 2007). The aim of this paper is to quantify the soil porosity (from 0 to 15 cm depth) with image analysis. Two soil surfaces were studied in relation with highland agriculture practices in the Nazas river watershed (Northern Mexico) that is one of the most important rainfall capture area in Northern arid of Mexico.

Methods

The study zone is located in the upper watershed of the Nazas river (Durango, Mexico) corresponding to a highland volcanic area of the Sierra Madre Occidental extended on 18321 km^2 with an altitude between 1600 and 3200 meters above the sea level (Figure 1).

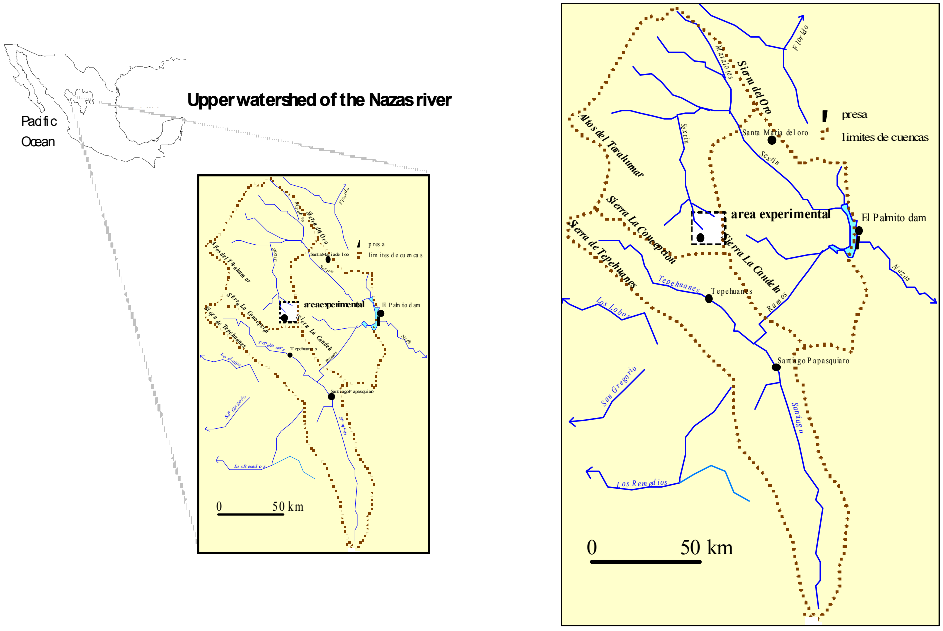

Figure 1. The study zone

Climate is from semiarid to sub-humid with temperature average between 15.9°C and 13.3°C; rainfall average are from 500 to 900mm respectively. Rainfall precipitation produces a great amount of hydrological runoff (up to 1200 million m^3) towards the great regional dam "Lázaro Cardenas" in order to supply water for irrigated lands of the bottom (Comarca Lagunera) region (Descroix *et al.* 2004).

Two soil surfaces related to highland agriculture where selected for analyzing soil porosity. They have the following characteristics:

1) Soil surface on well conserved (good state) grassland, with a vegetal cover from 75 to 100 % dominated by "navajita" grass (*Bouteloa gracilis*) with a Mull humus level (Duchaufour 1995) of 1cm thick formed by grass residue moderately incorporated into the sandy loam texture soil "chromic Cambisol" (FAO 1998).

2) Soil surface on degraded grassland, with a vegetal cover from 0 to 25 % dominated by "navajita" grass (*Bouteloa gracilis*) overgrazed and over trampled by bovine cattle that gives to the surface a mineral almost bare appearance on a sandy loam textured "chromic Cambisol".

Both surfaces corresponding to the same kind of geological features; chromic Cambisol developed from tertiary volcanic rock (Riolythe-Ignimbrite). Each surface was sampled from 0 to 15cm depth in order to measure physicochemical measurements (bulk density, organic matter, and total carbonate content) and were taken with non perturbed monoliths (15x15x15cm) in order to characterize the soil porosity by the Vergière method (Bourrier 1965). In laboratory conditions the six monoliths were dehydrated with acetone replacement and were impregnated with polyester resin (Scot-Bader Crystic) with added fluorescent pigment (Uvitex) that is sensitive to ultraviolet light (Murphy *et al.* 1977) Monoliths were cut at four depth levels (2, 3, 12 and 13 cm) and polished in order to take digital photos with white and UV light for the image analysis process.

Digital images were taken with an Olympus camera with an optical sensor (CCD) of 4.1 mega pixel. Two spatial scales were used for this proposes: M1 scale (scenes of 127 x 95 mm) with a pixel size of 56 µm, and M2 scale (scenes of 13 x 10 mm) with a pixel size of 6 µm. Digital images were binary transformed with the Image analyze program (Pro Plus® v4.5 Media Cybernetics, Maryland, USA).

The total soil porosity in monoliths was calculated from bulk density measurements (ρd)

$$\eta = 1 - (\rho d / \rho r) \qquad (1)$$

Where: η is total porosity (in percent), ρd is bulk density and ρr is real density (2.65 g cm^3) according to literature.

Pores characteristics were defined according with size and shape parameters. Pore size is expressed by the section area of each image (Equation 2). This parameter was grouped into three classes for each scale (Table 1)

$$T = 4\pi \text{ (area)} \qquad (2)$$

Where: T is the pore size (in square millimeters), and area is the pore section surface according with Coster and Chermant (1985).

Pore shape is calculated by the longing index (*Ia*) according with the area and the pore section on image scene and according with equation 3 (Hallaire *et al.* 1997). This was grouped into three pore shape classes (Table 2)

$$F = (\text{perimeter})^2 / 4\pi \text{ (area)} \qquad (3)$$

Table 1. Pore size classification.

Size	Scale M1 Pore Class	Scale M2 Pore Class
Small	T3: < 2 mm^2	T6: <0.02 mm^2
Medium	T2: 2 to 10mm^2	T5: 0.02 to 0.1mm^2
Large	T1: >10 mm^2	T4: > 0.1 mm^2

Results

Table 3 shows the soil physicochemical characteristics in each surface. There are a little difference between the sand content (higher) and in the loam and clay contents (lower) of degraded grassland surface. On the contrary there are significant differences in organic matter content (OM) and bulk density values (Da) between both surfaces. Total carbonate content is low for both surfaces The OM and bulk density values are indicators of the soil's pore volume, nevertheless they do not give information about the size and shape of soil porosity. Digital image treatment quantify the size and shape of soil porosity.

Table 2. Pores shape classification.

Shape	Longing index
Round	< 5
Elongated	5 a 7
Irregular	> 10

Table 3. Soil physicochemical characteristics (from 0 to15 cm depth).

Studied surface	Sand	Loam	Clay	Texture	OM	Bulk Density	Tot Carbonate
	------------ % -----------				%	g/cm³	(%)
1. Good state grassland	68	14	18	Sandy loam	6.2	1.50	3.80
2. Degraded grassland	82	6	12	Sandy loam	1.4	1.80	5.97

Binary images from four depth levels are showed on Figure 2. A preliminary analysis of the porous media in each profile indicates a high relative abundance of soil porosity (dark areas) in the good state grassland surface. Figure 3 shows the soil porosity profile based on bulk density combined with image analysis.

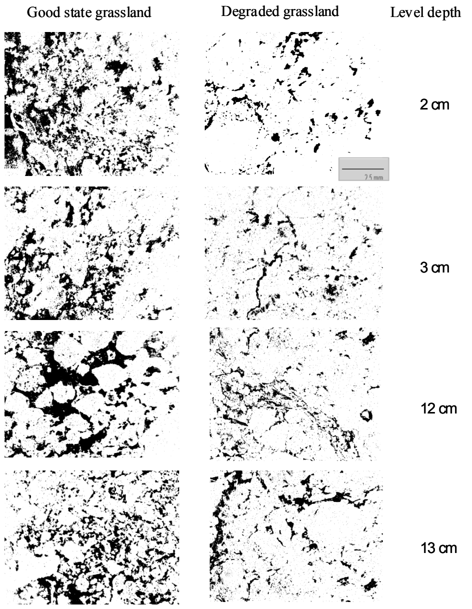

Figure 2. Soil porosity at M2 scale (13x10 mm scene size)

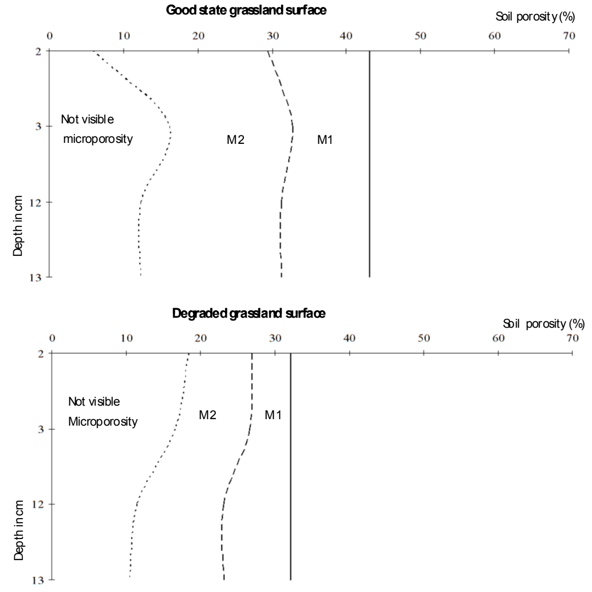

Figure 3. Soil porosity distribution in studied surfaces

The total soil porosity of good state grassland surface is larger than for degraded grassland (43 % versus 32 % respectively) and show a distribution of macro pores (M1 scale) with a rank from 10 to 13 % and a distribution of micro pores (M2 scale) with a rank from 16 to 23 %. On the contrary the degraded grassland surface shows a very dominant micro porosity from 0 to 3 cm depth; soil macro porosity is very reduced at the same level (5 % on M1 scale) but it increases (to 10 %) at 12 and 13 cm levels, with decreasing of cattle trampling influence. The frequency distribution of pores size and shape are shown in Figure 4. The histograms show six vertical bars corresponding to a six pore size classes (from T1 to T6 according to Table 1) and a subdivision into three pore shape classes (round, elongated and irregular). The good state grassland surface show higher percentages of large pores (T1 and T4 classes). Macro-porosity tends to disappear for the degraded grassland surface (T1 and T2 classes) that is dominated by smaller pores (T3 and T6 classes). The small pore class T3 (smaller than 2mm^2) shows a similar proportion in all the soil profiles of good state grassland. For both studied surfaces, round and irregular pores are dominant over elongated shape pores that are present in a lower proportion. Irregular pores are mainly in T1, T2 and T4 classes representing larger size pores. Round pores are dominant in T3, T5 and T6 classes corresponding to smaller pore sizes. Elongated pores are more frequent in T3, T4 and T5 classes. In conclusion, the studied surfaces have differences in terms of total soil porosity as well as pore size and shape. These differences certainly affect water and air flux within the soil of the watershed that is important to quantify.

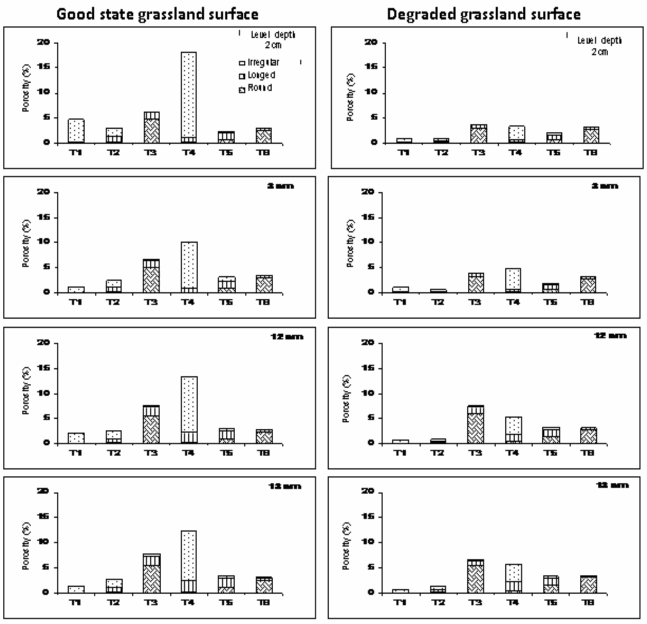

Figure 4. Size and shape of soil pore classes

Conclusions

The studied grassland surfaces have different porous media that could be related to their condition: good state grassland surface has a dominance of macroporosity characterized by irregular pores in relation to the importance of grass roots penetrating the soil surface and causing good aeration and water circulation. In contrast, degraded grassland surface shows a reduced pore volume dominated by round micropores that reveal physical compaction (by cattle trampling). The image analysis applied in this study shows clearly the qualitative and quantitative differences of soil porosity between two kinds of soil surface that are related to land use intensity in highland agriculture of Northern Mexico.

Physical degradation of soil surface observed here reveals the necessity managing about agriculture practices in highlands specially cattle grazing intensity. The hydrological repercussions of increasing degraded areas can be easy imagined. A stronger control of agriculture practices must be encouraged in order to keep this important zone in good condition.

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Status and soil management problems of highland agriculture of the main mountainous region in the South Korea

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Abstract

A survey of the status and soil management problems of highland agriculture of the main mountainous region in S. Korea was attempted. The acreage of the highland agricultural farmland above elevation of 600 m producing high value vegetable was 9.3% of the total upland of the surveyed area. The major crops were Chinese cabbages, radishes and potatoes. Onions, carrots, water melons, red peppers, tobacco, apples, strawberries, and various crops were in minor. Since more than 20% of the farmlands were on the steep or very steep slope classes, the soils might be subject to severe water erosion, where immediate conservation practices should be necessary. The major problems in vegetable cropping of the surveyed area were poor soil management against soil erosion and heavy application of fertilizers. In this area, the phosphate, calcium and potassium contents were much higher than the national average of the surface soils of Korea. The farmer's application amount of nitrogen fertilizer ranged up to 1.4 times the recommended level by soil test, These rates of phosphate and potassium were 6.5 and 2.7 times, respectively. Heavy fertilizer application might cause soil accumulation of nutrients, and water pollution problems due to eroded soil materials. The total cost for recommended conservation practices on farm was 29.2 million US$, while that for reforestation for severely eroded farmland on steep slope was estimated as 1,218 million US$.

Key Words

Highland agriculture, soil erosion, fertilizer use, nutrient accumulation, reforestation cost.

Introduction

High value vegetable production in uplands above 600 m of elevation is classified as 'highland farming', and the uplands between 400 and 600 m elevation was classified as the sub-highland farm in South Korea. The major crops are high value vegetables including Chinese cabbages, radishes, potatoes, and other horticultural crops including flowers. The farming demands high input of nutrients. As these farmlands are located on high mountain slope, the soils are subject to severe erosion that causes non-point source problems of water body of the downstream (Jung *et al.* 1998; Park 2002). Especially, the Baegdu main mountainous area is the most important subject area for soil and water conservation project and the main source of the two main rivers, the Han River and the Nagdong River in Korea (Jung *et al.* 2006). Eroded soils cause serious water quality problems and sedimentation in water body of the down streams. Reforestation of such problem land should be dealt as national political approach (Gerhard 2004). A field survey was performed to identify soil management problems involved in this special crop production area, and costs of conservation management practices to protect soil erosion and water quality were estimated.

Methods

From the detailed soil survey map of Korea, the acreage of uplands is located in highlands of 32 Local Provinces in respect to elevation and slope classes. The present farm management practices and soil management problems were surveyed through farmer's interview, and soil samples were taken. The chemical and physical properties of the soil samples were analyzed using NAIST recommended methods (NAIST 2000a). The cost of reforestation of the upland subject to severe erosion, and to install on-farm conservation practices were estimated.

Results

Acreage distribution of vegetable farmland with respect to elevation and slope classes

The highland agricultural farmland above elevation of 600 m producing high value vegetable was 9.3% of the total upland of the surveyed area (Table 1). The major crops were Chinese cabbages, radishes and potatoes. The minor crops included Onions, carrots, water melons, red peppers, tobacco, apples, strawberries, flowers, and etc. The 85% of the highland farm above elevation of 600 m were in Gangwon Province.

Table 1. Area and elevation class distribution of vegetable farmlands in the survey area.

	Elevation (m)					
	<200	200 ~ 400	400 ~ 600	600 ~ 800	800<	Total
Area[A]	116,645	100,401	44,375	21,898	4,957	288,276
(ha)	(40.5) [B]	(34.8)	(15.4)	(7.6)	(1.7)	(100)
Crops	Major crops: Chinese cabbages, radishes, potatoes Minor crops: Onions, carrots, water melons, red peppers, tobaccos , apples, strawberries, flowers and etc.					

[A] From the detailed soil survey map (NAIST 2008)
[B] Percentages were in parentheses

Table 2 shows areal distribution of the farmlands in the surveyed area. 84% of farmland was located on a slope over the 7 %. More than 20% were on the steep or very steep slope classes. This implies that these soils might be subject to severe water erosion, where immediate conservation practices would be necessary.

Table 2. Distribution of the farmlands in the surveyed area.

	Slope class						
	Plain (0 ~ 2%)	Weak slope (2 ~ 7%)	Mild slope (7 ~ 15%)	Moderate steep (15 ~ 30%)	Steep (30 ~ 60%)	Very steep (>60%)	Total
Area[A]	9,354	36,785	72,867	108,556	57,295	3,418	288,276
(ha)	(3.2)	(12.8)	(25.3)	(37.6)	(19.9)	(1.2)	(100)

[A] From the detailed soil survey map (NAIST 2008)
Percentages were in parentheses

Soil management problems

The major problems in vegetable cropping in the highland agriculture of the surveyed area were poor soil management against soil erosion and heavy application of fertilizers. Figure 1 shows present status of crop cultivation in a highland farming, and soil erosion severity of a sloped land with bare soil. The soil erosion problem should be the first soil management problem in this area. The estimated soil erosion potential calculated by RUSLE ranged from 31 to 205 T ha/yr (data were not shown). The main problem of severe erosiveness was on steep and long slope, plowing up and down, and uncontrolled during bare fallow period.

Figure 1. Status of highland agriculture producing high value crops above 600 m elevation in Korea. Well controlled contour culture (left), and uncontrolled water erosion from bare soil (right).

In this area, the phosphate and calcium and potassium contents were much higher than the national average of surface soil of Korea (Table 3). Farmers used excessive fertilizers as shown in Table 4. The farmer's application amount of nitrogen fertilizer ranged up to 1.4 times to the recommended level by soil test. That of phosphate and potassium were 6.5 and 2.7 times, respectively, and, thus, excessive nutrient accumulation occurred The surface soil eroded from the farm with high organic matter and phosphate, and excessively used fertilizers should affect water quality of downstream. Immediate conservation action to protect water quality might be necessary.

Table 3. Soil chemical characteristics of the survey farm.

Soil properties		Highland agriculture		National average	
		Surveyed farms	Gangwon[A]	Upland[B]	Forest[B]
pH		5.7	6	5.5	5.5
OM(mg /kg)		28.5	21	23.1	50
Avia-P_2O_5 (mg /kg)		776	544	161	33.7
Exchangeable cations	Ca	6.1	4.8	4.8	4.6
(cmol /kg)	Mg	1.5	1.1	2	1.7
	K	1.2	0.7	0.3	0.4

[A]Gangwon Agricultural Science and Technology Institute

[B]A-horizons of the upland and forest soils from the Detailed Soil Survey Maps (NIAST 2008)

Table 4. Comparison of fertilizer use of farms and recommended amount based on soil test.

Crop	Fertilizer application (N-P_2O_5-K_2O kg/ha)		
	Recommended (A)	Farmers application (B)	B/A
Potatoes	137-33-114	245-203-203	1.8-6.1-1.8
Chinese Cabbages	238 -30–71	365-236-281	1.5-7.9-4.0
Radishes	252-30- 68	304-203-202	1.2-6.8-3.0
Carrots	180-40-74	263-208-247	1.5-5.2-3.3
Onions	233-30-155	276-199-254	1.2-6.6-1.6

A : Recommended amount of N, P_2O_5, and K_2O by soil test

B : Average amount of fertilizers by farmers in the Gangwon highland area

Cost necessary for reforestation of the severe erosive farmland.

Table 5 shows total cost necessary budget for conservation practice needs on farm application immediately of the total highland agricultural land of 71,643 ha above 400 m elevation. The cost required for the conservation practices was 29.15 million US$. Table 6 shows the cost of reforestation of farmlands where severe erosion might occur of which slope exceeded 30%. The total object acreage that required immediate conservation action was 6,375 ha. The total cost for reforestation for these acreage was 1,218 million US$ including land price and reforestation costs. This cost was 40 times to the conservation practices in Table 4. Additional initiatives for farmer were not included. Since the local government could not pay all these costs, the Government of Korea should take this cost into account as the national budget. Strong support might be necessary.

Table 5. Required on-farm conservation practices to reduce erosion from the severely erosive farmlands in the surveyed area.

Conservation practices[A]	Required (m)	Unit price (US$/m)	Estimated Budget (million US$)
Buffer strip	655,752	5.05	3.31
Vegetative drainage	139,686	20.51	2.86
Intercept back drainage	313,041	28.01	8.77
Boundary end ridge	227,080	7.87	1.79
Boundary end ridge with stone mesh beds	93,124	114.04	10.62
U side drain	27,192	17.17	0.47
Stone wall backslope	15,043	88.32	1.33
Total			29.15

Total object farmland : 71,643 ha

[A]Recommended conservation practices by Park (2002)

Table 6. Cost necessary for reforestation of the severe erosive farmland.

Slope Class	Object acreage (ha)	Cost (million US$) forestation		
		Land price	Reforestation	Total cost
30~60%	4,398	567	274	841
60%<	1,977	193	123	590
Total	6,375	821	397	1,218
Remarks	Severely erosive Farm	12.9 US$/$m^2$ (GDI 2006)	6.2 US$/$m^2$	

Acknowledgment

This research was conducted by support of Rural Development Administration and Kangwon National University.

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Phosphorus transport through surface runoff and sub-surface drainage from regular free drainage and controlled drainage with sub-irrigation systems in corn and soybean production

C.S. Tan and T.Q. Zhang

Abstract

Majority of the field water discharge was from sub-surface tile drainage for both CDS and RFD systems. Controlled drainage with sub-irrigation reduced the flow volume of and the P content in tile drainage water, and consequently the total soil P loss, relative to RFD. Along with the enhancement of crop production due to timely supply of soil moisture, CDS can be recommended as a beneficial management practice.

Key Words

Phosphorus transport, surface runoff, sub-irrigation systems, corn and soybean production

Introduction

It is understood that non-point sources of agricultural lands have increasingly become important as sources of phosphorus (P) pollution to the water resource. The regions in southern Ontario are dominated with annual crops that are grown in soils which have a high risk of P loss due to both long-term build-up of P in soils and high volume water discharge from the farm lands. The effects are especially apparent in the Lake Erie basin, where some of Canada's most intensive agricultural activity combines with growing urbanization. The majority of soils in the region are tile drained and also prone to preferential flow through cracks, earthworm and root channels, and that can funnel water from the surface to the tile drainage, especially after a heavy rainfall.

Conservation tillage or no-tillage has been widely adopted for highly erodible soils in the Midwest of United States, and has been considered as best management agricultural practices for reducing soil erosion, which reduces soil P loss accordingly. On the other hand, other studies have reported that dissolved reactive P concentrations and losses increase in no-till fields. While conservation tillage reduces soil erosion and surface runoff, it also enhances infiltration. As a result, more nutrients, such as nitrate and P, and/or herbicides would find their way down to the sub-surface drainage and eventually to the groundwater. Agricultural sub-surface drainage is necessary for economical and efficient crop production in Southern Ontario. Unfortunately, such an approach can also increase non-point source agricultural pollution by enhancing the movement of agricultural sediment, nutrients and pesticides into surface and ground water resources. Research results indicated that controlled drainage provided some reduction in nitrate-N losses over conventional free drained crop land. With controlled drainage/sub-irrigation system, water is pumped back into the tile drains during water deficit periods to provide irrigation water directly to the crop root zone. This innovative water management system has both economic and environmental benefits.

The objectives of this research were to compare the effectiveness of the regular free tile drainage and controlled drainage-subsurface irrigation systems for: i) mitigating P losses from agricultural fields; and ii) assessing and identifying the proportions of soil P loss in surface runoff and sub-surface tile drainage flow.

Materials and methods

The experiment was initiated in the spring of 2000 and continued till the December of 2004 on a Perth clay soil (Gleyed Grey Brown Luvisol) that is located on the Essex Region Conservation Authority Demonstration Farm at Holiday Beach, Ontario, Canada. Cropping system was corn-soybean rotation. Corn was planted on May 26, 2000, May 20, 2001 and May 15, 2003. Fertilizer was applied pre-plant at 17.7 kg N/ha, 76.8 kg P/ha and 17.7 kg K/ha. Urea-Ammonium Nitrate (UAL 28% liquid) was added as a side-dress application in June at 150 kg N/ha. Soybeans were planted on June 1, 2002 and June 15, 2004.

The treatments included two water management systems: controlled tile drainage/sub-irrigation (CDS) and regular free tile drainage (RFD). Each plot was 25 m wide by 131 m long, and linked to a central automated monitoring station. The plot was tile-drained by six 104-mm diameter subsurface drains (4.6 m spacing, 0.6 m average depth). Each plot was equipped with a 0.6 m diameter catch basin at its lower boundary to collect surface runoff water. The sub-surface tile drainage at the CDS plot was routed to a control drainage structure before linked to central monitoring station. The control structure was used for both controlled drainage and subsurface irrigation. For controlled drainage, a "riser" within the structure increases the elevation of the tile outflow, thereby effectively raising the elevation of the tile and encouraging water retention within the soil profile. For subsurface irrigation water was pumped into the control structure, thus creating a pressure head that forces water back up the tile lines and into the crop root zone. The control structure was used primarily for subsurface irrigation during the growing season and primarily for controlled drainage during the fall, winter and spring.

Surface runoff and sub-surface tile drainage were directed to a central monitoring station. Four stainless steel custom fabricated tipping buckets were used to measure surface runoff and tile drainage volume on a year-round continuous base. The tipping buckets were calibrated individually to determine the relationship between flow rate and tip rate. The data logger was used with tipping buckets to measure flow volume on a continuous base. Samples of surface runoff and tile drainage water from each plot were collected using two separate ISCO auto-samplers. Sample collection was based on flow volume. After volume recording and sampling, water was pumped into a constructed reservoir, and then used for subsurface irrigation of the CDS plot during the growing season.

The water samples were analyzed for dissolved reactive P (DRP) and total dissolved P (TDP), which was performed by digesting vacuum-filtered sub-samples with acidified ammonium persulphate ($(NH_4)_2S_2O_8$) oxidation in an autoclave. Total P (TP) in water samples was measured by digesting a sub-sample of unfiltered water using the H_2O_2-H_2SO_4 method. Phosphorous concentrations in all solutions were determined using a QuikChem Flow Injection Auto-Analyzer with the ammonium molybdate ascorbic acid reduction method. Dissolved un-reactive P (DURP) was determined as the difference between TDP and DRP. Particulate P was determined as the difference between TP and TDP. Flow weighted mean (FWM) P concentrations for each plot were calculated as cumulative loss (on mass basis) from June 1, 2000, to December 31, 2004, divided by the corresponding cumulative water outflow from the plot.

Results

The CDS system produced greater surface runoff but much less sub-surface tile drainage relative to the RFD system over a 5-yr period from June 1, 2000 to December 31, 2004. Sub-surface tile drainage accounted for 80 and 97% of total flow volume for the CDS and RFD systems, respectively.

For RFD, FWM of DRP, DURP, PP and the total P (TP) concentrations over the 5-yr period were averaged at 0.057, 0.057, 0.627, and 0.741 mg P/L in surface runoff water and at 0.034, 0.053, 0.393, and 0.480 mg P/L in tile drainage water, respectively (Table 1). Controlled drainage with sub-irrigation increased FWM of most forms of P and the TP concentrations in surface runoff water, but decreased the FWM of DURP, PP and the TP concentrations in tile drainage water.

Cumulative total DRP, DURP, TDP, PP and TP losses were attributed to sub-surface tile drainage at 65 to 71% for the CDS system and at 95 to 97% for the RFD system (Table 2). The CDS system produced greater cumulative DRP, DURP, TDP, PP and TP losses in surface runoff but much large reduction on cumulative DRP, DURP, TDP, PP and TP losses in sub-surface tile drainage relative to the RFD system. The cumulative total PP losses accounted for more than 80% of total TP losses for both the CDS and RFD systems. Combined with surface and sub-surface water, the CDS system reduced PP and TP losses by 15 and 12 %, respectively relative to the RFD system. Since the major soil P losses pathway was through sub-surface tile drainage, the CDS water management system that enhance crop growth and nutrient uptake and alter the hydrology of surface runoff and tile drainage flow can be used to reduce off-field movement of soil P loss. The effectiveness of the CDS system for soil P transport reduction in our soil and climate conditions may be further modified and improved by optimizing the tile spacing and depth.

Conclusions

Majority of the field water discharge was from sub-surface tile drainage for both CDS and RFD systems. Controlled drainage with sub-irrigation reduced the flow volume of and the P content in tile drainage water, and consequently the total soil P loss, relative to RFD. Along with the enhancement of crop production due to timely supply of soil moisture, CDS can be recommended as a beneficial management practice.

Table 1. Flow weighted mean (FWM) P concentration for dissolved reactive P (DRP), dissolved un-reactive P (DURP), total dissolved P (TDP), particulate P (PP), and total P (TP) from surface runoff and tile drainage under controlled drainage/sub-irrigation (CDS) and regular free drainage (RFD) systems from June1, 2001 to December 31, 2004.

	CDS					RFD				
Year	DRP	DURP	TDP	PP	TP	DRP	DURP	TDP	PP	TP
	FWM P in surface runoff (mg P/L)									
2000	0.010	0.131	0.141	1.573	1.714	0.014	0.023	0.037	1.076	1.113
2001	0.102	0.067	0.169	0.450	0.619	0.076	0.093	0.169	0.597	0.766
2002	0.059	0.063	0.123	0.527	0.650	0	0	0	0	0
2003	0.151	0.117	0.268	0.324	0.592	0.065	0.027	0.092	0.350	0.442
2004	0.119	0.042	0.161	0.406	0.567	0.110	0.056	0.166	0.669	0.835
FWM Ave	0.094	0.090	0.184	0.620	0.804	0.057	0.057	0.114	0.627	0.741
	FWM P in tile drainage(mg P/L)									
2000	0.022	0.088	0.110	0.293	0.403	0.029	0.023	0.052	0.440	0.492
2001	0.040	0.040	0.080	0.301	0.381	0.050	0.042	0.092	0.399	0.491
2002	0.064	0.077	0.141	0.367	0.508	0.039	0.061	0.100	0.430	0.530
2003	0.036	0.026	0.062	0.370	0.432	0.040	0.067	0.107	0.310	0.417
2004	0.042	0.037	0.079	0.418	0.497	0.020	0.051	0.071	0.411	0.482
FWM Ave	0.043	0.045	0.087	0.370	0.457	0.034	0.053	0.087	0.393	0.480

Table 2. Dissolved reactive P (DRP), dissolved un-reactive P (DURP), total dissolved P (TDP), particulate P (PP), total P (TP) and percentage of P loss from surface runoff and tile drainage under controlled drainage/sub-irrigation (CDS) and regular free drainage (RFD) systems from June1, 2001 to December 31, 2004.

	CDS					RFD				
Year	DRP	DURP	TDP	PP	TP	DRP	DURP	TDP	PP	TP
	P loss in surface runoff (g P/ha)									
2000	3.3	42.7	46.0	514.1	560.1	1.2	2.0	3.1	91.6	94.8
2001	70.0	45.2	115.2	307.2	422.4	12.9	15.9	28.8	101.9	130.7
2002	15.8	16.8	32.6	140.2	172.8	0.0	0.0	0.0	0.0	0.0
2003	77.0	59.5	136.5	165.0	301.5	5.8	2.4	8.2	31.2	39.4
2004	10.9	3.8	14.7	37.1	51.8	1.4	0.7	2.1	8.3	10.3
Total	177.0	167.9	344.9	1163.6	1508.5	21.3	21.0	42.2	232.9	275.1
	P loss in tile drainage(g P/ha)									
2000	7.5	29.8	37.3	99.5	136.9	12.5	9.7	22.2	189.5	211.7
2001	82.8	84.4	167.1	630.5	797.6	120.1	102.1	222.2	962.6	1184.8
2002	64.7	78.8	143.5	373.2	516.7	71.7	112.1	183.8	795.1	978.8
2003	18.6	13.6	32.2	391.5	423.7	88.1	147.0	235.1	682.9	918.0
2004	152.1	136.4	288.5	1332.2	1620.7	89.7	223.5	313.3	1821.3	2134.6
Total	325.7	343.0	668.7	2826.8	3495.5	382.1	594.4	976.6	4451.4	5428.0
	P loss in both surface runoff and tile drainage (g P/ha)									
2000	10.8	72.6	83.4	613.6	697.0	13.7	11.7	25.4	281.1	306.5
2001	152.8	129.5	282.3	937.6	1219.9	133.0	118.0	251.0	1064.5	1315.5
2002	80.5	95.6	176.1	513.4	689.5	71.7	112.1	183.8	795.1	978.8
2003	95.6	73.1	168.7	556.5	725.2	93.9	149.4	243.3	714.1	957.4
2004	163.0	140.2	303.2	1369.3	1672.5	91.1	224.2	315.3	1829.6	2144.9
Total	502.7	510.9	1013.6	3990.5	5004.1	403.4	615.4	1018.8	4684.3	5703.1
	Percentage of P loss									
Surface	0.35	0.33	0.34	0.29	0.30	0.05	0.03	0.04	0.05	0.05
Tile	0.65	0.67	0.66	0.71	0.70	0.95	0.97	0.96	0.95	0.95

Three alternative crops to reduce soil erosion for mountain agriculture in Gangwondo, Korea

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Abstract

Alternative cropping that might reduce soil erosion and could ensure farm income in this mountainous highland agricultural region was tried. Three edible wild plants; goatsbeard, Korean thistle, and aster, were selected to test as alternative crops to reduce soil erosion in mountain agriculture of highland area in Gangwondo, Korea. The soil losses from the alternative cropping were 28 to 61 percent of the soil loss from summer radish cultivated by conservation tillage with contour and plastic film mulching. The relative soil losses in the second year ranged from 2.8 to 5.5 percent in comparison with radish cultivation. Rapid surface coverage by these alternative crops resulted in continuous soil loss protection. Greater residue, no-till, and vigorous root growth also contributed the reduced soil loss. Farm net profit of these crops was greater than for radish. At least three year cultivation, however, might be necessary for economic cultivation of goatsbeard or aster due to low or no yield in the first year.

Key Words

Soil loss, alternative crops, edible perennial plants, mountain agriculture, highland.

Introduction

Mountain agriculture of highland area in Korea has been mostly depended upon vegetable crop production such as Chinese cabbages and radish ensuring high income, but involves management problems due to severe erosion. One half of the highland agricultural lands of South Korea are distributed in Ganwondo (Jung *et al*. 1998, 2006). The eroded soils and runoff have caused pollution problems in running water. For an example, muddy water caused by heavy rain in the 2006 summer growing season in the upper stream area of the Soyang River Basin in Gangwondo lasted for more than 9 months until late March of 2007 increasing turbidity of running water from 3.1 NTU in 2005 to 55.8 NTU in 2006 (Gangwondo 2008), and thus protecting measures to reduce soil erosion are urgently need (Jung *et al*. 2006, Lee 2006). This research is to develop an alternative crop that might reduce soil erosion and could ensure farm income in this mountainous highland agricultural region. Edible wild plants could be alternative cover crops for this purpose. Three edible wild plants; goatsbeard, Korean thistle, and aster, were selected to test as alternative cropping to reduce soil erosion in mountain agriculture of this highland area in Korea.

Methods

Planting

Three edible wild perennial plants including goatsbeard (*Aruncus diocicus var. kamrschaticus* H. Hara), Korean thistle (*Cirsium setidens* Nakai), and aster (*Aster scaber* Thunb), were selected to test as alternative crops comparing effectives with radish (*Raphanus sativus*) in the experimental farm located on Jawoonri, Hongcheon, Gangwondo, from 2006 to 2009. Table 1 shows surface soil characteristics of the experimental farm.

Table 1. Surface soil characteristics of the experimental farm.

pH (1:5)	EC (dS/ m)	OM (g/kg)	Av-P_2O_5 (mg/kg)	Exchangeable cations ($cmol^+/kg$)			Particle size distribution (%)		
				Ca	Mg	K	Sand	Silt	Clay
5.5	0.13	18.5	409	2.9	0.8	0.9	59	25	16

The 8 plots with 18 m length and 3 m width were formulated on 18.5 % slope, partitioned by the plastic board of 30 cm height. Three alternative crops, goatsbeard, Korean thistle, and aster were panted compared with radish with two replications. The goatsbeard was transplanted on May 11 2007 at the planting density of 60-cm X 30-cm. The seedlings were grown up by seedling box. The Korean thistle and aster were transplanted at the planting density of 50-cm X 20-cm on the same date. The seedlings were grown up by pot raising. The compost fertilizers were applied at 7 MT/ha and NPK fertilizers at the rate of 336 kg/ha of nitrogen by urea, 50 kg/ha of phosphate as super phosphate, and 276 kg/ha of potassium as potassium chloride were used before transplanting. Radish were seeded on June 5 2007, and June 24, 2008 at the planting density of 70-cm X 25-cm by contour planting with plastic film mulching as conservation farmers used to take to do.

Soil loss and runoff monitoring

Soil loss and runoff during the growing periods were monitored at each rain events by simple runoff collector (Pinson *et al*. 2004) installed in each plot (Figure 1). The amounts of soil loss and runoff were weighed in laboratory.

Figure 1. Simple soil loss and runoff collector installed in the plots.

Crop growth, coverage and yield

Growth of crops and canopy coverage were measured seasonally. The lengths of stem and leaves were measured. Surface coverage of canopy was measured indirectly through pixel analysis of photographs taken at the 2 m above the canopy taking green pixel number 75 to 85 being plant cover. Yield of crops were measured after harvest.

Results

Effect of alternative crops on soil loss

Table 2 and 3 show cumulative soil loss during the cropping period in 2007 and 2008 comparing that from radish cultivated by conservation tillage with contour cropping and plastic mulching. The cumulative soil loss from radish in 2007 was 6 MT/ha. The relative soil loss from the Korean thistle plot was 28 percent of that from radish plots, 36 percent from goatsbeard plots, 61 percent from aster plots. In 2008, the cumulative soil loss from radish was 12 t/ha. The relative soil loss from the Korean thistle, goatsbeard, and aster ranged from 2.8 to 5.5 percent of the soil loss from radish cultivation. Changes in crop coverage (Figure 2) show the surface crop coverage in 2007 and 2008. Crop coverage of the three alternative crops increased rapidly as plant stands expanded. Since these alternative crops were perennial plants, the surface coverage in 2008, the second year of cultivation, rapidly increased to over 80 percent before heavy rainy season begun, and reached almost 100 percent in July. This successful coverage reduced soil erosion by 95 percent. Additionally, greater plant residue remained in the following spring from the three wild crops compared with radish. Moreover, little soil disturbance from no-till for the wild crops resulted in less soil loss. Goatsbeard showed vigorous root growth and effectively retained soil particles, resulting in enhanced soil erosion protection.

Table 2. Effect of alternative cropping to reduce soil loss in mountain agriculture in 2007.

Precipitation event			Soil loss (kg/ha)			
Date of collection	Period	Rainfall (mm)	Goats-beards	Korean thistle	Aster	Radish1)
Jul 20, ’07	Jul 10~Jul 19	101.7	88	74	136	226
Aug 2, ’07	Jul 24~Aug. 1	90.6	517	422	591	1,306
Aug 9, ’07	Aug. 2~Aug 8	150.6	766	552	1,470	2,415
Aug11, ’07	Aug 9~Aug 10	165.1	645	498	1,568	206.6
Cumulative		508.0	2,026	1,546	3,765	6,006
Relative soil loss (%)			35.5	28.0	60.6	100

[1] Summer radish were cultivated

Table 3. Effect of alternative cropping to reduce soil loss in mountain agriculture in 2008.

Precipitation event			Soil loss (kg/ha)			
Date of collection	Period	Rainfall (mm)	Goats- beards	Korean Thistle	Aster	Radish
Jul 21, '08	Jul 13~Jul 21	113.4	35	25	30	343
Jul 26, '08	Jul 22~Jul 26	195.2	141	185	211	2,923
Aug 3, '08	Jul 30~Aug 3	63.1	138	90	37	2,507
Aug 23, '08	Aug 9~Aug 23	169.5	358	169	75	6,496
Cumulative		541.2	672	469	354	12,269
Relative soil loss (%)			5.5	3.9	2.8	100

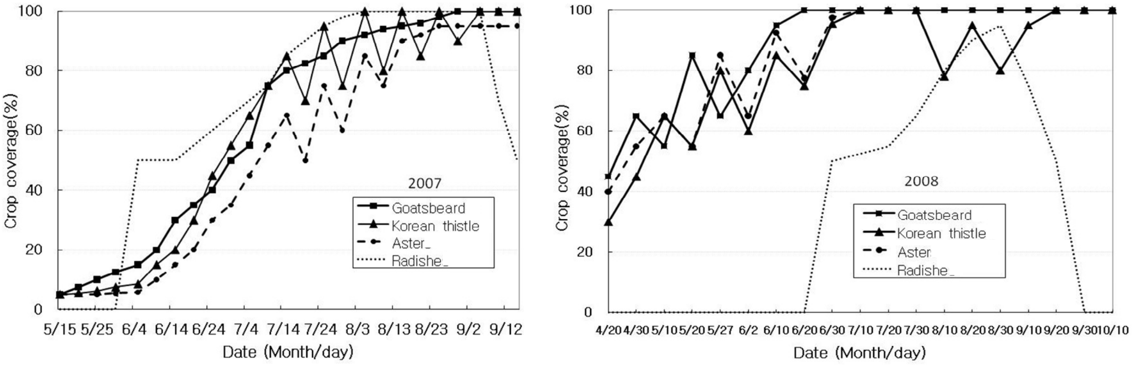

Figure 2. Changes in crop coverage during the cropping period in 2007 (left) and 2008 (right).

Yield and economic feasibility of alternative crops

Table 4 shows yield of three alternative crops, and their net profit from cultivating the crops in comparison with summer radish. Average yield of goatsbeard in 2007 and 2008 was 4.4 t/ha, and the farm net profit was 13.1 thousand US$ per ha. No economic value of yield was observed in the first year of cultivation. The average farm net profit of Korean thistle and aster for three years was 14.8 and 9.3 thousand US$ per ha, respectively. These values were greater than that of the summer radish. For goatsbeard and aster, it is necessary to cultivate for at least three years to get profit due to low or no yield in the first year. The yield of Korean thistle, however, decreased substantially from 16.0 t/ha in the second year to 6.3 t/ha in the third year.

Table 4. Fresh yields of the crops and their economic value.

Crops	Yield (t/ha fw)				Farm profit (X 1000 US$)			
	2007	2008	2009	Average	2007	2008	2009	Average
Goatsbeard	-	4.21	4.60	4.41	- 7.65 [1]	22.31	24.56	13.07
Korean thistle	14.47	15.96	6.30	12.24	14.63	23.36	6.46	14.81
Aster	4.72	11.80	11.09	9.20	- 3.39 [2]	16.29	15.06	9.32
Radish	41.86	41.91	43.79	42.52	9.25	8.39	4.98	7.54

[1] Cost only due to no crop yield. [2] Greater cost than income.

Conclusion

Three perennial wild edible plants goatsbeard, Korean thistle, and aster could be cultivated as alternative crops to reduce soil loss from the mountain agricultural area in highland of Korea. The soil losses from these alternative plants were 28 to 60 percent of the soil loss from summer radish cultivated by conservation tillage with contour and plastic film mulching. The relative soil losses in the second year ranged from 2.8 to 5.5 percent in comparison with radish cultivation. Successive soil loss protection by these alternative crops was due to rapid surface coverage. Farm income values of these crops were higher than that of radish. However, a three year rotation might be necessary for economic cultivation of Korean thistle or aster due to decrease in yield caused by continuous production.

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Use of Caesium-137 technique for the assessment of soil erosion in two selected sites in Uma Oya Catchment in Sri Lanka

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Abstract

The ^{137}Cs technique for investigating rates and patterns of soil erosion has now been successfully applied in a wide range of environments. ^{137}Cs is a product of atmospheric nuclear testing, which commenced in the 1950s. ^{137}Cs strongly adheres to soil particles and therefore can be used as a tracer in soil movement studies. Soil erosion rates in two different land use types with no soil conservation methods common in the Uma Oya catchment located in the up country of Sri Lanka have been investigated using the ^{137}Cs technique. The soils in these sites were Humults, locally referred to as red-yellow podzoilc soils. The ^{137}Cs content in soil was measured using core samples obtained up to a depth of 35 cm. The mean reference inventory was 753 Bq/m^2 and showed exponential decline with depth. The mean ^{137}Cs inventory in the two study sites were 290 and 491 Bq/m^2. This corresponded to an average soil loss rate of 44 t/ha/yr and 24 t/ha/yr, respectively. These results were comparable to erosion data obtained using the conventional methods. This method is very effective in finding the range of soil erosion rates at different areas and different land uses for proposed developmental projects so that steps could be taken by the policy makers for prevention of soil degradation.

Key Words

Caesium-137, Uma Oya, reference inventory, exponential decline, soil erosion

Introduction

Soil erosion and associated land degradation are major environmental problems encountered worldwide in the development of agriculture. Soil erosion and deposition cause not only on-site effects, but also off-site problems such as downstream sediment deposition in fields, floodplains, and water bodies. The use of fallout radionuclide ^{137}Cs affords an effective and valuable means of studying erosion and deposition within the landscape. ^{137}Cs technique has now been used to investigate soil erosion and redistribution in many areas in the world (Colling *et al.* 2001).

^{137}Cs has a half life 30.17 years. Absence of any natural source of ^{137}Cs in the environment, strong and rapid adsorption to soil particles and its relatively long half life makes ^{137}Cs a suitable tracer for soil erosion and sedimentation studies. The technique is based on comparing the ^{137}Cs inventory (Bq/m^2) at a given location with that of a nearby 'reference' location (Walling and Quine 1990b). A loss or gain of the ^{137}Cs inventory at that location in comparison with the inventory at the reference location represent an erosion or a sedimentation. These comparisons of measured inventories with the local reference values provide useful qualitative information on the spatial distribution of erosion and deposition in the landscape. The derivative of quantitative estimates is required to obtain the magnitude of the soil erosion and associated land degradation. Walling and He (2001) provide a useful review of many different approaches which have been used to convert ^{137}Cs measurements to quantitative estimates of soil erosion and deposition rates. The key advantage of this technique is that it provides retrospective information on medium-term (30-40 years) erosion/deposition rates and spatial patterns of soil redistribution without the need for long-term monitoring programme.

Therefore this study was undertaken for the preliminary assessment of soil erosion in a small catchment in Sri Lanka, using ^{137}Cs technique. The proportional model described by Walling and He (2001) was used to convert the ^{137}Cs measurement to erosion data.

Study site

The area selected for this study was the Uma Oya catchment in Nuwara Eliya District in Sri Lanka. The Nuwara Eliya district is in the upcountry of Sri Lanka, at an elevation of about 1900m above sea level. The Uma Oya is estimated to have a total catchment area of about 740 km^2 and forms one of the main tributaries of the Mahaweli river. This catchment has a variety of land uses. The highest elevation of the catchment is covered by natural forest. In addition to this, the catchment is occupied by tea estates, rice, potato, vegetable and home-garden cultivation on steep slopes without any effective soil conservation measures. In this catchment, two cultivated sites, one with potato and other under pasture, were selected for study. Undisturbed reference sites were selected according to the criteria described by Pennock and Appleby (2002). The forest site, located close to the selected cultivated sites at a higher elevation, was identified for establishing the reference ^{137}Cs inventory. The dominant soil in this area was referred to as red-yellow podzolic soils (Pannabokke 1996).

Materials and Methods

Sampling methods for determining fallout radionuclide inventory

Sampling programme for the reference site was carried out using the procedures described by Owens and Walling (1996). The samples were taken by the scraper plate method at 2 cm intervals up to 40 cm to determine the appropriate depth of penetration of ^{137}Cs. The area of the scraper plate was 50 ×20 cm^{2}. In order to define the spatial variability of soil ^{137}Cs inventory, bulk soil cores were collected from five transects in a 40 m× 50 m grid network. The core area was 88.0 cm^{2}. The cores were collected to a constant depth of 35 cm. Each transect consisted of 4 sampling points with the spacing of 10 cm. At each sampling point, three cores were collected within an area of 1 m^{2}. The three replicated samples were mixed and one composite sample was made for each sampling point.

Sampling strategy in cultivated sites

Two cultivated sites were selected to measure the soil erosion rates. The bulk soil cores were obtained using the cylindrical core sampler used in the previous section. The cores were taken from 20 sampling points in three transects placed in a zigzag manner. The spacing between two sampling points was 3.0 m and the total sampling area was 20 × 20 m^{2}.

Sample preparation and analysis

Soil samples were air dried, disaggregated and passed through 2 mm mesh to separate the gravel from soil. A sub sample from the weighed fine fraction was filled into a Marinelli beaker whose geometry was similar to that used for system calibration. The activity of ^{137}Cs was measured using a Hyper Pure Germanium (HPGe) detector with the relative efficiency of 30% and the resolution of 2.20 keV at the gamma energy of 1332.5 keV of ^{60}Co. The detector was surrounded by a 10 cm thick lead shield, to reduce the background. Each sample was counted for 20 hrs. The background of the system was measured using an empty Marinelli beaker. A mixed radionuclide standard (LU 466) obtained from the International Atomic Energy Agency was used for the efficiency calibration. The reference material, IAEA Soil - 6 of known ^{137}Cs content was used for method validation. The net area under peak at 661.5 keV was used to determine the ^{137}Cs concentration of soil in Bq/kg. The spectra were analyzed using the software packages Genie 2000. The minimum detection activity of ^{137} Cs was 0.4 Bq/kg for the counting time and the geometry used. The areal activity of ^{137} Cs was calculated using the equation:

$$S = cmA^{-1} \qquad (1)$$

Where c is the ^{137}Cs concentration in the sample < 2mm (Bq/kg), m is total sample dry mass of the fine fraction (kg) and A is the cross-section area of the sampling device (m^{2})

Estimation of soil erosion rates

The proportional model was used to quantify the erosion rates in this study.

Results and discussion

The depth distributions of ^{137}Cs at the reference site is shown is Figure 1. The vertical distribution of ^{137}Cs obtained at the reference sites is similar to that obtained from undisturbed sites by other workers (Walling and Quine 1990b; Owens and Walling 1996). The total ^{137}Cs inventory in depth incremental samples was 772 ± 88 Bq/m^{2}.

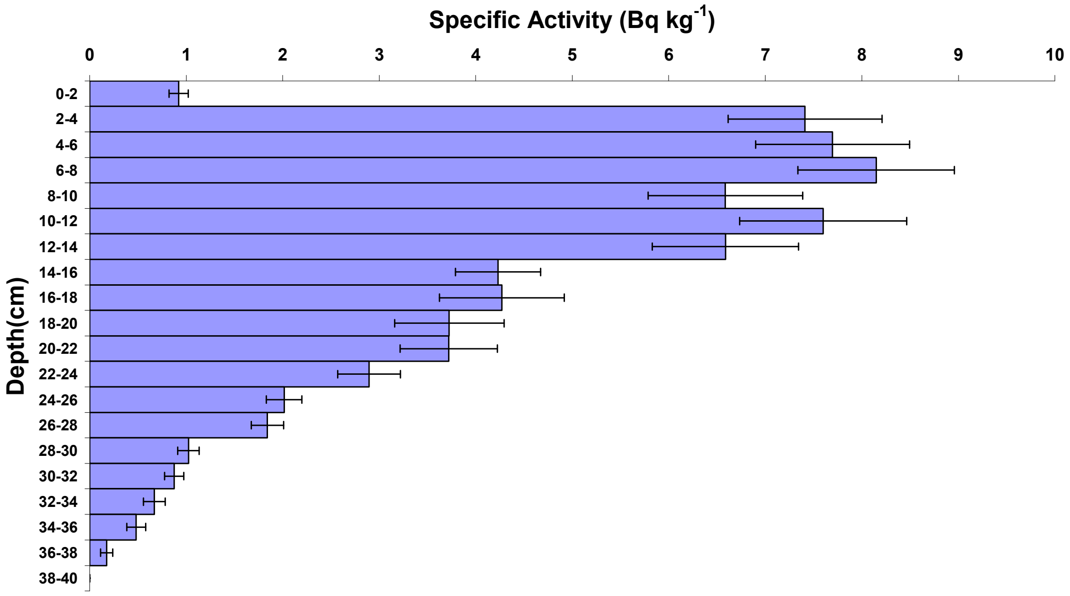

Figure 1. The depth distribution of ^{137}Cs within the soil profile at the reference site.

For bulk samples, a mean reference inventory of 753 Bq/m^2 was obtained. The coefficient of variation was 17.32% and the standard error was 30 Bq/m^2. Based on the approach of Owen and Walling (1996) where the reference inventory is expressed as the mean ± 2SEM the ^{137}Cs inventory at the reference site range from 693 - 813 Bq/m^2.

The mean reference value of 753 Bq/m^2 was used to determine the percentage loss or gain of ^{137}Cs at the respective study site. The mean ^{137}Cs inventory at the potato cultivation site and the pasture site were 290 Bq/m^2 and 491 Bq/m^2 respectively. Figures 3 and 4 indicate the ^{137}Cs activities (Bq/m^2) of each sampling points in potato and pasture sites respectively. The calculated mean erosion rate in the potato cultivated site was 44 t/ha/yr where as for the pasture site it was 24 t/ha/yr.

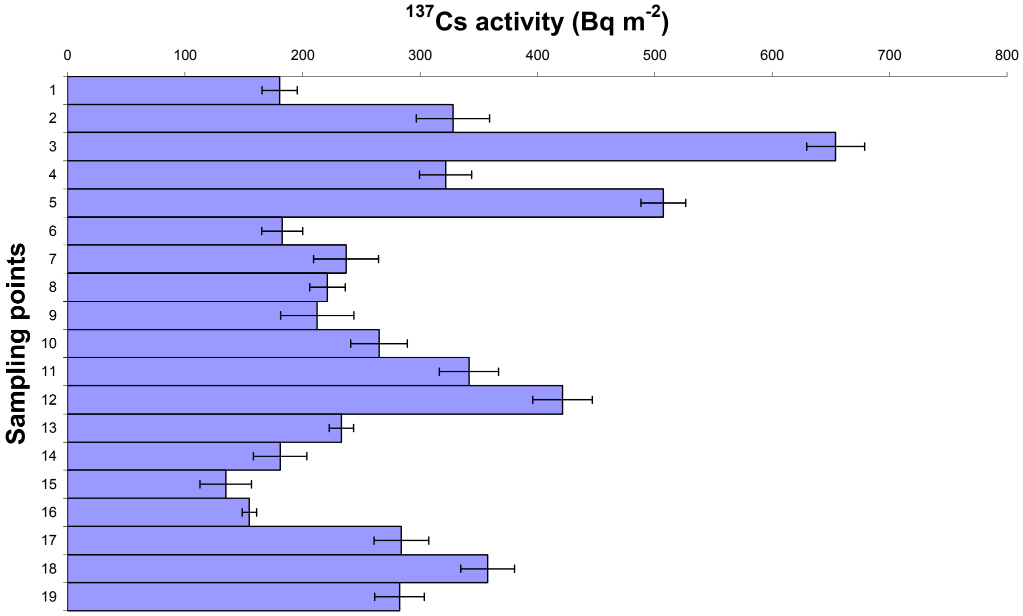

Figure 2. ^{137}Cs activities under potato cultivation.

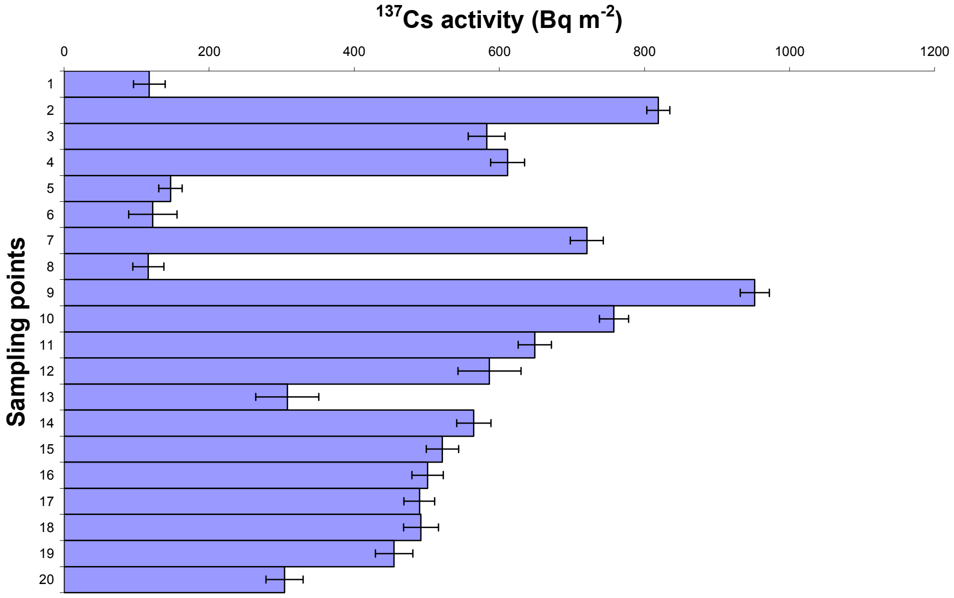

Figure 3. ^{137}**Cs activities in under pasture.**

Conclusions

This study investigated the possibility of using ^{137}Cs measurements to quantify soil erosion in two cultivated sites in Sri Lanka. The results confirm the significance of soil erosion. These preliminary results display considerable potential for the use of ^{137}Cs technique for further soil erosion and redistribution studies in Sri Lanka.

Acknowledgements:

Assistance with the field work from the staff of the Land Use Division, Department of Irrigation, and the assistance in ^{137}Cs measurements from the Nuclear Analytical Section, Atomic Energy Authority and the Department of Nuclear Science, University of Colombo are gratefully acknowledged.

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Water and fuel saving technologies: Unpuddled bed and strip tillage for wet season rice cultivation in Bangladesh

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Abstract

Shortages of water and the rapid spread of two-wheel tractors (2WT) have created the opportunity to develop locally-adapted conservation agriculture (CA) techniques for crop establishment by rice-based smallholders in South Asia. During 2009, the wet season rice (*Oryza sativa* L.) was transplanted into minimum tillage puddled; unpuddled-bed and strip tillage conditions in the drought-prone area of Bangladesh, to assess establishment methods that could reduce crop production cost and water use. Land preparations were done by the 2-WT operated, Versatile Multi-crop Planter (VMP) recently developed by CIMMYT, Bangladesh. Tillage treatments did not influence the shoot dry matter production. There was 65 % less diesel fuel required in the strip tillage treatment than with beds formed by VMP. Labour requirement for land preparation in beds formed by a shaper were 4.5 times higher than single pass puddling and beds formed by VMP. Time required to transplant seedlings was almost doubled in unpuddled plots relative to puddled plots. Weeding cost was higher in beds formed by VMP and strip tillage plots compared to other tillage treatments. Regardless of tillage treatment, 41-43 % less irrigation water was used by crops established by VMP planting operations as compared to a traditional tillage system.

Key Words

Versatile Multi-crop Planter, drought, bed formation, transplanted rice

Introduction

The northwest region of Bangladesh has drought prone areas, even though mean annual rainfall is 1645 mm (BMDA 1995). This area is covered with thick clay layers, which have low permeability. At the same time, the average depths of the deep tubewells already sunk into the soil are greater in comparison with other areas of Bangladesh (Khan *et al.* 1997). Due to uneven distribution of rainfall and limited availability of surface water, groundwater becomes the main source of irrigation water. Climate change, particularly higher temperatures, and higher rates of groundwater withdrawal may exacerbate drought during cool and dry seasons. Lower rainfall reduces recharge to the aquifers. The water table is declining and many of the tubewells are inoperable in the dry season (Bhuiyan 1982). Moreover, at the end of the transplanted rice season, puddled paddy fields dry and form cracks. The cracks accelerate water evaporation. The hard, dry surface of such soils hindered crop establishment until the introduction of 2-WT for cultivation. Presently, more than 0.35 million Chinese-made 2-WTs are being used in Bangladesh for agricultural purposes (Haque *et al.* 2004). Conservation agriculture helps farmers to reduce production costs while maintaining or increasing crop yields, and improving soil health, crop diversity and timeliness of cultivation. The CA technologies like reduced tillage, strip tillage, bed planting, and direct seeding might be applicable to conditions in northwest Bangladesh. Successful development of 2-WT based implements, zero tillage, strip tillage, minimum tillage and bed planters in Bangladesh have created several avenues for the pursuit of CA. However, farmers could only afford to engage in CA if they could purchase a single implement able to perform many operations. Thus, the 2-WT tractor operated VMP was developed with the provision to use adjustable row spacing of crops for zero tillage, strip tillage, minimum tillage, bed planting, and even conventional tillage operation; seeding and fertilizer application occur simultaneously in a single pass operation (UNAPCAEM 2009). A single tillage system is not feasible for all soils and climatic conditions. Therefore, the choice of the best suited tillage system must be appropriate for the particular agroecological environment. In this study, different tillage systems were compared in wet season rice during 2009 for establishing rice in a drought-prone zone of Bangladesh.

Methodology

The experiment was conducted at the Bangladesh Rice Research Institute (BRRI), Regional station, Rajshahi. The study area lies at 24°69´N and 88°30´E. Agroclimatic (rainfall, evapotranspiration and thermal condition) data were collected from the BRRI weather station. Initial bulk density in 0-7.5 cm depth was 1.21 (g/cm^3) at 39.7 % gravimetric water content and bulk density in 7.5-15 cm depth was 1.51 (g/cm^3) at 26.3 % gravimetric water content. The soil pH and organic carbon in the experimental field were 7.96 and 7.9 g/kg, respectively.

Four tillage treatments in the experiment were: (i) Single pass puddling by 2 WT (T_1); (ii) Single pass puddling by 2 WT followed by bed formed by operating a shaper tool manually 8 days after transplanting (T_2); (iii) Bed formed by VMP in single pass (T_3) and; (iv) Strip tillage by VMP in single pass (T_4). The plot size was 221 m^2. Before transplanting, land was leveled in the puddled plots. Two persons were engaged in the leveling operation. One labourer was needed to pull the shaper in the puddled field. The shaper was operated in the field three times to form a good bed shape. Wet season rice (July – November) grown was BR11, a popular high yielding variety. Thirty-five day old seedlings were transplanted in all tillage treatments. Seedlings were transplanted into puddled conditions (T_1 and T_2) or unpuddled conditions (T_3 and T_4). The treatments were arranged in a randomized complete block (RCB) design. The seedling spacing for T_1 and T_2 was 25 x 15 cm, and 20 x 15 cm for T_3 and T_4. In the T_2 and T_4 treatments, the width of beds and furrows were 35 cm and 20 cm, respectively. Data on task time, fuel consumption and agronomic performance were collected from all treatment plots. Derived-carbon dioxide emissions from field operations were calculated from the diesel used in tillage operation using the conversion factor of 2.6 kg of CO_2 per kg of diesel consumed (Greece 2003). Duncan's Multiple Range Test (DMRT) was used to determine the significant differences among the treatments.

Results and discussion

Fuel consumption

Fuel consumption was significantly higher (26.8 l/ha) in T_3 treatment than other treatments (Table 1). Fuel consumption in T_4 treatment was lowest (9.5 l/ha) among the tillage treatments i.e. 65 % less fuel was required compared to T_4. Conventional puddling required 16.5 l/ha whereas, tilling and seeding operation done by 2 WT operated seeder (PTOS) in single pass operation saved 40 % of diesel fuel per hectare per year (Miah *et al.* 2008). Carbon dioxide emission was higher (69.7 kg/ha) in T_3 treatment whereas CO_2 emission was lower in T_4 treatment (24.7 kg/ha) (Figure 1). Conventional puddling was done by 2 WT and required 4-5 passes to make a favourable condition for establishing transplanted rice. Strip tillage method reduced by 65 and 48 % CO_2 emission as compared to the bed by VMP and single pass puddling operations, respectively.

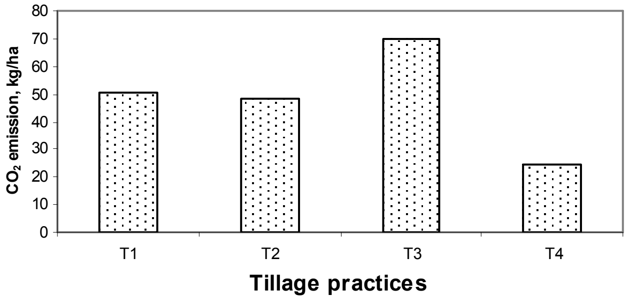

Figure 1. Effect of tillage practices on carbon dioxide emission.

Field capacity

Tillage treatments had a significant effect on the field capacity (Table 1). Field capacity of VMP during bed formation in a single pass was lowest i.e. (0.065 ha/hr). Conventionally, a farmer would use 6-8 tillage passes, 2-3 leveling passes and 50-60 man days labour (0.002 hr/ha) to make a bed. Whereas, the field capacity of 2 WT using the rotavator to puddle the plot in a single pass operation was 0.166 ha/hr.

Labour requirement in land preparation and transplanting

Land preparation included tillage operation by VMP and puddling, leveling and shaper operation manually. Labour requirement for land preparation in T_2 treatment was 4.5 times higher than in T_1 and T_4 (Table 1). There was no significant difference in labour requirements for land preparation between T_1 and T_4. The greatest time was required for transplanting seedlings in T_4 (296.1 man-hr/ha) i.e. almost double the time needed in T_1 and T_2 (Table 1). Poor visibility of strips under muddy flood water caused difficulties for people when transplanting seedlings in the hard surface of untilled soils. Similar problems were encountered when transplanting seedlings in T_3. The whole plot was inundated one day before transplanting so the soil was not soft enough to push the seedling roots into the soil easily.

Table 1. Tillage effect on fuel consumption, field capacity, labour requirement in land preparation and transplanting.

Treatment	Fuel consumption (l/ha)	Field capacity (ha/hr)	Labour requirement (man-hr/ha)	
			Land preparation	Transplanting
T_1	19.5 ab	0.166 a	19.2 c	151.1 c
T_2	18.6 b	0.160 ab	85.5 a	168.2 bc
T_3	26.8 a	0.065 c	32.3 b	200.6 b
T_4	9.5 c	0.109 bc	19.0 c	296.1 a

In a column, means followed by a common letter are not significantly different at 5 % level by DMRT.

Irrigation water savings

CA tillage treatment types did not have any significant effect on irrigation water requirement during wet season rice cultivation, but about 41-43% less water was required compared to reports from a conventional tillage system by Rashid (2005) (Table 2). Lowest water usage was required in T_3 (614 mm). Rahman and Islam (2008) observed that 37 % water usage can be saved if rice is transplanted in a bed as compared to the conventional tillage system without sacrificing grain yield during the dry season (January to May).

Table 2. Water requirement in different tillage system.

Treatment	No. of irrigation	Irrigation water, mm	Effective rainfall^1, mm	Total water, mm	Water savings (%)
Conventional tillage*	Not available	207	775	1082*	-
T_1	10	260	376	636	41
T_2	10	254	376	630	42
T_3	10	240	376	614	43
T_4	10	247	376	623	42

*Rashid (2005), ^{1}http://www.alanasmith.com/theory-Calculating-Effective-Rainfall.htm

Effect of tillage on plant height, number of tillesr per hill, and crop growth rate

Numbers of hills/m^2 were significantly different in the tillage plots due to varied line spacing (Table 3). Number of hills/m^2 was higher (30.8) in strip tillage plots than others. Tillage treatments had a significant effect on plant height up to 55 days after transplanting (DAT)(Table 3). The number of tillers/hill increased with time, up to 40 DAT, during which time there was also a significant effect of tillage treatment on tiller number/hill. After 40 DAT, the numbers of tiller per hill declined and tillage treatment had no significant effect on tiller number per hill in 55 DAT. This suggests an overriding effect of plant competition among the tillers by 55 DAT. Regardless of tillage treatment, shoot dry matter of plants per ha were similar, up to 55 DAT.

Table 3. Effect of tillage on plant height, number of tillers per hill and shoot dry matter.

Parameter	DAT	Tillage treatment			
		T_1	T_2	T_3	T_4
No. of hill/m^2	0	23.4 b	23.2 b	22.2 b	30.8 a
Plant height, cm	20	36.7 a	35.7 a	36.4 a	34.2 b
	40	60.9 b	61.6 a	59.1 c	56.8 d
	55	81.0 a	81.4 a	79.4 ab	77.5 b
	65	83.7 a	83.8 a	82.4 ab	80.1 b
No. of tiller/hill	20	10.2 a	9.8 a	10.2a	7.8 b
	40	20.7 ab	20.7 ab	22.4a	18.1 b
	55	19.3	19.8	21.1	17.3^{NS}
	65	18.2 b	19.3 ab	20.4 a	16.3 c
Shoot dry matter, kg/ha	20	434	331	370	375
	40	2927	2570	2452.	3080
	55	5370	5912	5475	6109

In a row, means followed by a common letter are not significantly different at 5 % level by DMRT. NS- Not significant

Cost of land preparation and transplanting, weeding and irrigation under different tillage system

Highest land preparation cost was incurred by the T_2 treatment (49 US$/ha) and lowest cost (14 US$/ha) by T_4 because of low fuel and labour requirement. Tillage treatment had a significant effect on transplanting cost (Table 4). Transplanting cost was highest in T_4 because more time was needed to transplant seedling in unpuddled conditions. Weeding cost was highest in T_3 and T_4. Tillage treatment had no significant effect on irrigation cost.

Table 4. Cost of land preparation and transplanting, weeding and irrigation (US$) under different tillage systems.

Parameter	Tillage treatment			
	T_1	T_2	T_3	T_4
Land preparation	21 c	49 a	31 b	14 c
Transplanting	43 c	48 bc	57 b	84 a
Weeding	65 b	58 b	194 a	166 a
Irrigation	17	16	15	15

In a row, means followed by a common letter(s) are not significantly different at 5 % level by DMRT.

Conclusion

Regardless of the form of CA tillage treatment, about 41-43 % less water was required compared to a conventional tillage system. Lowest water usage was required in the beds formed by the shaper treatment (614 mm). Fuel consumption had significant variation among the treatments, with 65 % less fuel required in strip tillage treatments by VMP. However, labour use was higher for transplanting and weeding in unpuddled strip tillage. Irrespective of tillage treatment, shoot dry matter production was similar up to 55 DAT. Initial results indicate that the VMP could be used in multiple modes for crop establishment of rice, i.e., strip tillage, minimum tillage, bed formation and conventional tillage.

Acknowledgement

The authors acknowledge the continuous support from Dr. MA Rahman, PSO and Mr. Biswajit Karmaker, SSO, BRRI to execute the CA research.

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Water erosion modeling in a watershed under forest cultivation through the USLE model

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Abstract

The modeling of erosion processes integrated with a Geographic Information System (GIS) has been an important tool to assess erosion by water. The objective of this study was to determine the spatial distribution of water erosion in forest ecosystems and generate soil loss prediction maps according to different land use scenarios. The study was conducted in a watershed occupied by *Eucalyptus* cultivation located in Belo Oriente, in the Rio Doce river valley, Central-East region of Minas Gerais state, Brazil. For the spatial distribution modeling of soil loss for the watershed, the USLE model was applied coupled with Geographic Information System (GIS). The lowest soil loss, among the scenarios evaluated, was predicted for the land use of *Eucalyptus* with conservationist-practices, *Eucalyptus* with non-conservationist-practices, and native forest, indicating a strong influence of the vegetation cover, expressed by the USLE C-factor, in guaranteeing a good protection for the soil and conservationist use practice efficiency in controlling water erosion.

Key Words

Latosol (Oxisol), Cambisol (Inceptsol), tolerance of soil loss, sediment, canopy, Digital Elevation Model (DEM).

Introduction

Currently, forest plantations in Brazil covers 5.7 million hectares, generates 4.5 million direct and indirect jobs and contributes to more than 2% of GNP (Gross National Product) (Hoeflich and Tuoto 2008). Minas Gerais is the state with the highest planted eucalyptus forest area in Brazil. According to the report of the Minas Forestry Association (MFA), the annual planting of forests in the State increased five and a half times in one decade, from 35,789 hectares, in 1999, to 198,500 hectares in 2008 (Celulose Online 2009). Most of those plantations are concentrated in the areas of the Rio Doce river valley, Central-West, Northeast, Central/North and the Jequitinhonha/Mucuri valley (Minas Gerais 2008). The Rio Doce river valley, currently, is one of the most degraded areas in the state of Minas Gerais, due to water erosion.

According to the current market demands, in terms of sustainable production, erosion by water should be considered a priority, since it is the consequence of inappropriate land use. Soil is considered a non-renewable resource, and sediment is largely responsible for compromising the amount and quality of the water and silting the water bodies. As a form of aiding in the identification of areas with high and low susceptibility to water erosion and to understand the erosive mechanisms, as well as their causes and effects, water erosion modeling has been used. Erosion process modeling can be used as an environmental indicator of specific management zones and in the determination of conservation practices. The most used model throughout world is the Universal Soil Loss Equation-USLE (Wishmeier and Smith 1978), due to its simplicity. It is well known and studied, and it needs a relatively small quantity of information to make a prediction. With the advent of technology, many works integrating USLE factors with the Geographic Information System (GIS) have been developed with the aim to distribute spatially and predict soil losses for certain areas (Erdogan *et al.* 2007; Ozcan *et al.* 2008; Bahadur 2009; Beskow *et al.* 2009). The objective of this study was to determine the spatial distribution of water erosion in a forested watershed and generate soil loss prediction maps based on different land use scenarios, for the purpose of evaluating soil loss in case the current use (forest plantation) is changed.

Methods

The study was carried out in a watershed currently used as a *Eucalyptus* forest plantation, located in the municipal district of Belo Oriente (coordinates 19º13'12 S and 42º29'01 W), with an area of 21.22 km^2, located in Rio Doce river valley, central-east region of the Minas Gerais state, Brazil. The climate of the area is Aw, tropical with a dry winter followed by a rainy summer, according to Köppen classification, with the average temperature varying between 22 and 27ºC, the maxim being 32ºC and the minimum 18ºC. The average annual precipitation ranges from 701 to 1,500 mm and average altitude is 300 m. The soils were classified as very loamy texture Dystrophic Red Yellow Latosol - LVAd (Oxisol), very loamy texture typical Dystrophic Red Latosol - LVd (Oxisol), and very loamy texture typical Dystrophic Tb Haplic Cambisol - CXbd (Inceptisol) (Cenibra 2001) (Figure 1). The acceptable tolerance of soil loss by water erosion in the area, is 7.17 t/ha/yr for LVAd (Pires 2004), 11.22 t/ha/yr in LVd (Silva *et al.* 2002) and 8.79 t/ha/yr (Silva 2009).

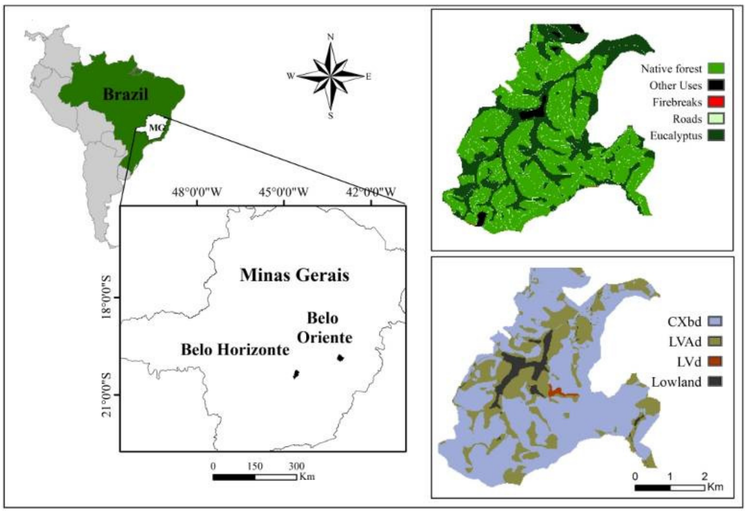

Figure 1. Localization of the municipality of Belo Oriente in Minas Gerais - Brazil, highlighting the soil map and the current land use of the watershed studied.

For the spatial distributed modeling of the soil losses in the watershed, the USLE was applied, which has the following expression (Wishmeier and Smith 1978):

$$A = R \times K \times LS \times C \times P \qquad (1)$$

where A is the average annual soil loss in t/ha; R is average annual rainfall erosivity factor in MJ·mm/ha/h/yr; K represents the soil erodibility factor in t·h/MJ/mm; LS corresponds to slope length (dimensionless) and slope steepness (dimensionless) factors; C is the cover management factor (dimensionless); and P is the support practice factor (dimensionless). The software Arc GIS 9.2 was employed and coupled the USLE factors with the geographic information system and map making.

R factor: utilized a value of 10,745 MJ·mm/ha/h/yr according to Silva (2009).
K factor: the values of 0.0001 and 0.0002 t·h/MJ/mm were used for LVd and LVAd (Silva 2009) and 0.024 t·h/MJ/mm for CXbd (Silva 2003). The K factor map was determined based on the soil map.
LS factors: for the calculation of the LS factors, a Digital Elevation Model (DEM) was generated with 24-m resolution, and from it the slope map was obtained. The slope length factor (L) was obtained through the following equation (Wischmeier and Smith 1978):

$$L = (\lambda/22.13)^m \qquad (2)$$

where: λ is the cell size; and m is slope length exponent determined by the following equations (Foster *et al.* 1977; McCool *et al.* 1989; Renard *et al.*1997).

$$m = \beta/\,(1+\beta) \qquad (3)$$

$$\beta = (\sin\theta/0.0896)/[3.0 \times (\sin\theta)^{0.8} + 0.56] \qquad (4)$$

where: β is the ratio of rill to interrill erosion, and θ (degrees) is the slope drop angle.
The slope steepness factor (S) was determined according to Foster *et al*. (1977); McCool *et al*. (1989); and Renard *et al*. (1997).

$$S = 10.8 \times \sin\theta + 0.3, \text{ for slopes} < 9\% \qquad (5)$$

$$S = 16.8 \times \sin\theta - 0.5, \text{ for slopes} \geq 9\% \qquad (6)$$

C factor: the C factor values used were 0.016, 0.012 and 0.052 for the *Eucalyptus*, native forest and planted pasture, respectively (Silva 2009). The C factor map was obtained from the current land-use map.
P factor: P = 0.5 was used for the scenario with conservationist *Eucalyptus* and P = 1.0 for the other scenarios according to Bertoni and Lombardi Neto (2005). The analyzed scenarios were: soil loss maximum

potential (bare soil, BS), current land-use level planted *Eucalyptus* (conservationist system, LPE), up and downslope planted *Eucalyptus* (non-conservationist system, DPE), land-use with native forest (natural system, NF), and land-use with planted pasture (main land-use in the area, PP).

Results

The spatial distribution of the soil loss under the current land-use, soil loss maximum potential, and soil loss from different scenario are in Table 1 and Figure 2. When the extension occupied by each erosion class among the scenarios evaluated, it was noticed that 75, 57, 61, 46, and 39% of the area was below the average tolerable soil loss values in the area, for LPE, DPE, NF, BS, and PP, respectively. These results were high to those obtained by Weill and Sparovek (2008), which found about 30% of the Ceveiro watershed area, in Piracicaba, to be below the soil loss tolerance value.

Comparing the simulation results among the current land-use scenarios (conservationist and non-conservationist *Eucalyptus*) and the other scenarios (Table 1), it was verified that the conservationist *Eucalyptus*, non-conservationist *Eucalyptus*, and the native forest presented soil losses below 12 t/ha/yr in most of their area (> 60% of the area), confirming the capacity of the cultivation of forest species to protect the soil in a manner similar to the native forest, by promoting surface drainage reduction through the rain drops interception by the canopy as well as by the litter. The planted pasture presented large soil loss areas with over 12 t/ha/yr, about 50%, indicating that the substitution of the current land-use by planted pasture did not show sustainable for that area, agreeing with Machado *et al*. (2003), who found soil loss increases in simulations conducted in a watershed in Piracicaba, Brazil, when the native forest was replaced with pasture.

Table 1. Percentage of area occupied by erosion class.

Class	Soil Loss	LPE	DPE	NF	PP	BS
	t/ha	--------------------	--------------------	%	--------------------	--------------------
1	0 - 1	37.6	35.3	35.7	34.7	18.5
2	1 - 3	13.0	5.9	8.3	3.7	6.0
3	3 - 6	12.4	9.3	9.4	4.1	7.4
4	6 - 9	11.9	6.5	7.5	3.6	6.9
5	9 - 12	12.0	5.9	7.5	4.6	5.0
6	> 12	13.3	37.2	31.7	49.4	56.1

LPE: land-use with level planted *Eucalyptus* (conservationist *Eucalyptus*); DPE: land-use with up and downslope planted *Eucalyptus* (non-conservationist *Eucalyptus*); NF: land-use with native forest; BS: bare soil (soil loss maximum potential); PP: land-use with planted pasture.

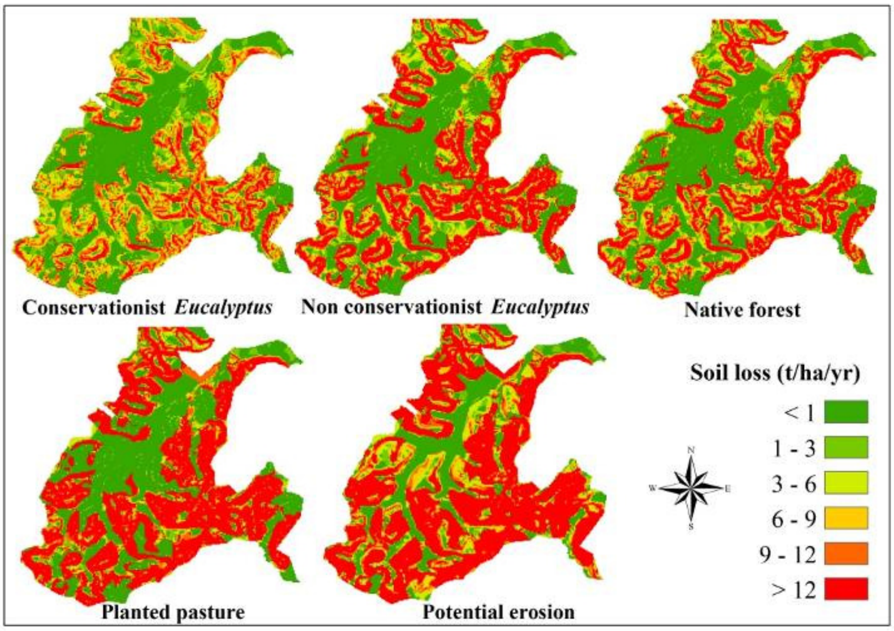

Figure 2. Soil loss in the different scenarios evaluated.

Conclusion

The least soil loss, among the appraised scenarios, occurred in the conservationist *Eucalyptus* land-use, native forest and non-conservationist *Eucalyptus*, indicating a strong influence of the vegetation cover, expressed by the USLE C-factor, in guaranteeing a good protection for the soil and conservationist use practice efficiency in controlling water erosion.

Acknowledgements

We thank Celulose Nipo-Brasileira (CENIBRA) for all support given to this work. In addition, we acknowledge the Research Foundation of the State of Minas Gerais (FAPEMIG) for financial support.

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Water, soil and phosphorus loss with cattle slurry application to Oxisols under no-tillage and natural rainfall

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Abstract

Milk dairy cattle production occurs in Paraná state, and the application to soils is an alternative for final disposal of the animal manure. This study aimed to evaluate the losses of soil, water and nutrients through runoff in a no-tillage system, under natural rainfall in a two soils with different doses of cattle slurry (0, 60, 120 and 180 m³/ha/yr). The experiment was carried out for two years in experimental areas being managed under no-till for over 12 years. The runoff was collected in 60 L containers after every rainfall event with occurrence of runoff. According to the data, 180 and 120 m³/ha/yr of cattle slurry are the best dose for the sandy clay loam and clay Oxisols, respectively, considering the two years of application, low slope (10%), low rainfall, and at least 10 days between the manure application and rainfall event. The flow-weighted average of dissolved, reactive phosphorus concentrations were above of the limit associated with eutrophication, indicating that even in unmanured no-till, the need for conservation practices to avoid the runoff for reach the water bodies.

Key Words

Runoff, manure, water quality, eutrophication, nutrients.

Introduction

The Paraná state, a pioneer in no-tillage in Brazil, is also an important milk dairy cattle producer, with mainly a confined system (free-stall). A concerning issue is the fate of the cattle slurry. Most of the manure is applied in areas under no-tillage, improving the levels of soil fertility and decreasing the mineral fertilizer costs. On the other hand, the manure applied to land is an important source of N and P, which can be carried by runoff to water bodies and cause eutrophication problems (Hooda *et al*. 2000; Shigaki *et al*. 2006), especially when there is no criterion of doses, period and form of application, as well as soil type, topography, soil conservation practices and distance from the field to the water body.

The objectives of this study were to evaluate the long term effect, loss of soil, water and nutrients through runoff in no-till systems, under natural rainfall in two Oxisols, a sandy clay loam and a clay, with low slope (10%) and different doses of cattle slurry (0, 60, 120, 180 m³/ha/yr), and to contribute to the best management practice definition.

Methods

Characterization of the area and treatments

The experiment was conducted at two stations, one with a sandy clay loam Oxisol, 13% slope, during November 2005 to May 2008, and another with a clay Oxisol, 10% slope, from May 2006 to May 2008. Both were under no-tillage for over 12 years. The plot area was 29.75 m^2 (9.0 m long and 3.5 m wide) bounded by metal plates of 10 cm in height with 5 cm under the ground. The last one meter was built in a "V" to collect the runoff in a 60 L container. The treatments consisted of four doses of liquid cattle manure (0, 60, 120, and 180 m^3/ha/yr), in four blocks, with half applied in the summer and half in the winter at the soil surface.

Collection and analysis of runoff

In the sandy clay loam Oxisol, the treatments were installed in November 2005, but due to low precipitation, runoff occurred only from September 2006 until May 2008. For the clay Oxisol, the treatments were installed in May 2006, and runoff occurred from September 2006 until May 2008. Runoff samples were collected after every rainfall event with occurrence of runoff. The minimal interval between the application of cattle slurry and the first rain was 10 days for both soils.

After the water loss determination, a runoff subsample from the 60 L container was collected for nutrient and soil loss analysis. After mixing the subsample well, a 30 mL aliquot was dried to determine the sediment concentration. Dissolved reactive phosphorus was determined by spectrophotometry after filtering a subsample through a 0.45 µm membrane (ascorbic acid method, American Public Health Association 1995).

Statistical analysis

To assess the effect of cattle slurry on soil and water loss and on the flow-weighted average concentration of dissolved reactive phosphorus, adjusted quadratic polynomial regression models were used with the program SIGMA PLOT ® Version 10.0 (Sigma Plot 2006).

Results

Soil losses (Figure 1) decreased with increasing doses of cattle slurry in the sandy clay loam Oxisol, however they were not statically significant in the clay Oxisol. Application of manure also decreased water loss (Figure 2), however, in the clay Oxisol the beneficial effect occur when 120 m^3/ha/yr dose was used, while for the sandy clay loam Oxisol, rates of 180 m^3/ha/yr were needed. Short-term experiments where rainfall occurred soon after the application of liquid manure resulted in high soil and water losses, possibly by the soil surface sealing, (Bertol *et al.* 2007; Mori *et al.* 2008). In long-term experiments, the application of manure improves the soil physical quality (Mellek *et al.* 2008) and consequently reduces runoff and soil loss (Smith *et al.* 2001). There is evidence that the longer the interval between the application of manure and the rainfall event the lower the water, soil and phosphorus losses (Gilley *et al.* 2007, Allen and Mallarino 2008).

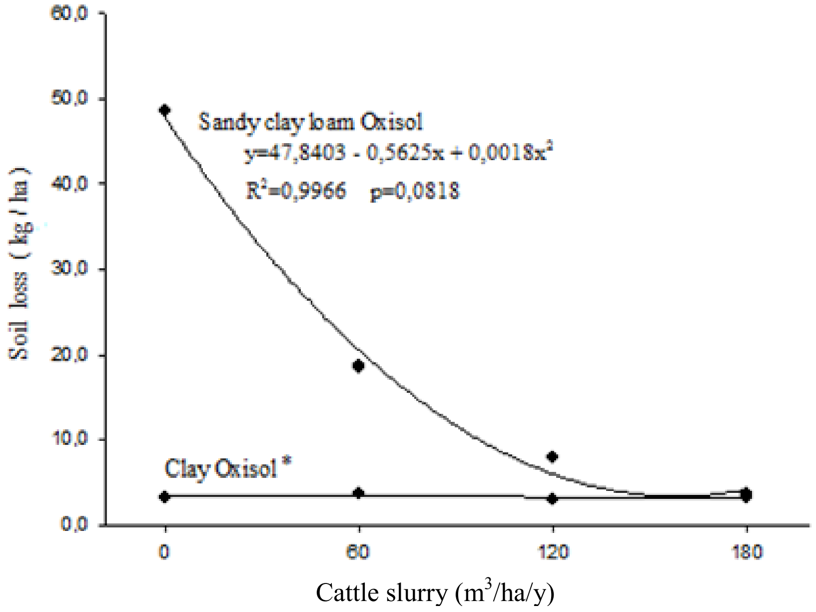

Figure 1. Total soil loss in sandy clay loam Oxisol and clay Oxisol with application of cattle slurry in a no-tillage system and natural rainfall.

The losses of dissolved reactive phosphorus (Figure 3) decreased up to a dose of 120 m^3/ha/yr for the clay Oxisol and up to 180 m^3/ha/yr for the sandy clay loam Oxisol. However, the flow-weighted average concentration of dissolved reactive phosphorus (Figure 4) increased with manure application in the clay Oxisol. For the sandy soil, the flow-weighted average concentration of dissolved reactive phosphorus reduced with the manure application up to the high dose.

Losses of phosphorus in all treatments did not reach 1% of total P applied, which is consistent with other studies (Sharpley *et al.* 1994; Mori *et al.* 2008), but the weighted average concentrations of DRP were above the maximum allowed by Brazilian legislation. Agronomical this loss is not significantly, but environmentally this loss is of concern if the flow reaches a water body.

Conclusion

The application of cattle slurry decreased soil, water and dissolved reactive phosphorus losses. According to the data, 180 and 120 m³/ha/year of cattle slurry are the best dose for the sandy clay loam Oxisol and clay

Oxisol, respectively, considering the two years of application, low slope (10%), low rainfall and at least 10 days between the manure application and rainfall event. The flow-weighted average concentration of dissolved reactive phosphorus was above the limit associated with eutrophication, indicating, even for unmanured no-till, the need for conservation practices to avoid runoff reaching water bodies.

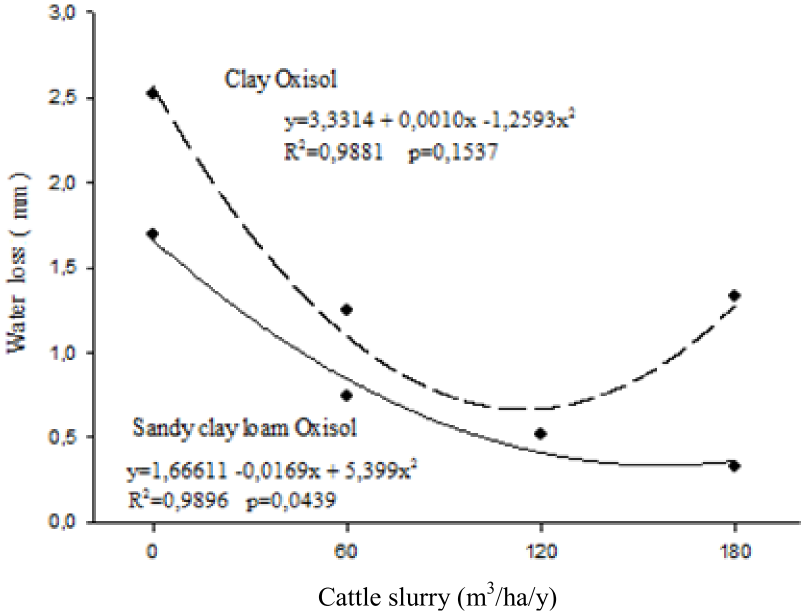

Figure 2. Total water loss in sandy clay loam Oxisol and clay Oxisol with application of cattle slurry in a no-tillage system and natural rainfall.

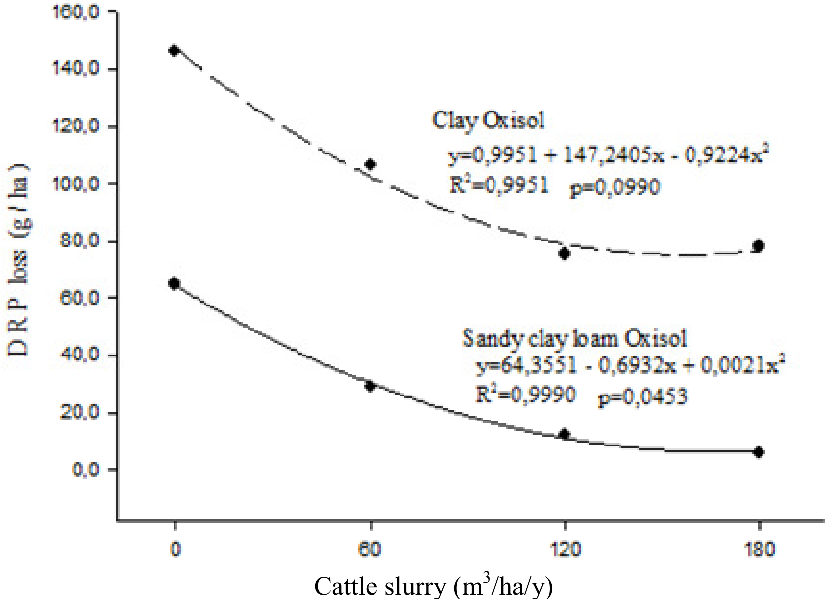

Figure 3. Dissolved reactive phosphorus (DRP) loss in sandy clay loam Oxisol and clay Oxisol with application of cattle slurry in a no-tillage system and natural rainfall.

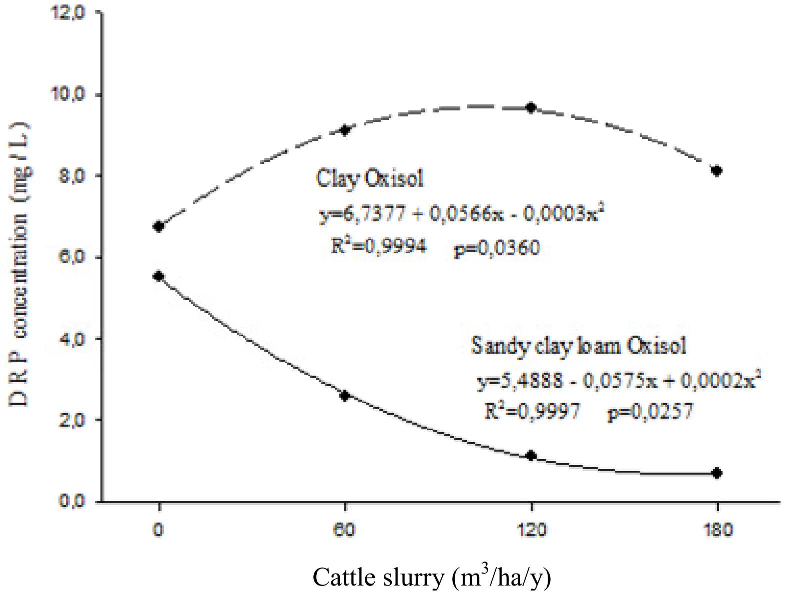

Figure 4. Flow-weighted average concentration of dissolved reactive phosphorus (DRP) in sandy clay loam Oxisol and clay Oxisol with application of cattle slurry in a no-tillage system and natural rainfall.

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