Crop production, nutrient recovery and hydrology following cattle feedlot manure application

Kaara Klepper[A], Riaz Ahmad[B] and Graeme Blair[B]

[A]Primary Industries and Fisheries, Department of Employment Economic Development and Innovation. Toowoomba Qld 4350, Email kaara.klepper@deedi.qld.gov.au
[B]Agronomy and Soil Science, University of New England, Armidale, NSW, 2351, Australia. Email gblair@une.edu.au

Abstract
A field plot experiment was established on a sandy loam Typic Natrustalf, duplex soil in Northern NSW, Australia in 1997, to determine crop response, nutrient recovery, and impacts on surface and subsurface water flow following the application of feedlot manure and effluent. Over the three year study, treatments included a control, (nil manure), moderate annual manure applications (20-25t DM/ha applied every year), a high initial application (60 t DM/ha applied in year 1 only) and an inorganic fertiliser treatment (N, P, K applied every year). Both the moderate annual and high initial manure treatments received supplementary inorganic N fertiliser in years 2 and 3. Successive forage crops of sorghum (*Sorghum bicolour* cv. Super-Dan) and triticale (*Triticosecale spp*.cv. Madonna) were grown with highest total dry matter yields recorded by the manure and inorganic treatments. The highest recovery of N, P and S was in the inorganic treatment (63%, 48% & 32%) and K from the high initial manure treatment (269%). Supplemental N applied to the moderate annual manure treatment tended to increase nutrient recovery mainly through increased yield. Total cumulative surface runoff ranked in descending order was control>inorganic>moderate annual>high initial manure treatment. The high initial manure treatment also recorded the lowest total cumulative subsurface flow (95mm) compared to all other treatments (mean 150mm).

Key Words
Manure, crop production, nutrient recovery, hydrology

Introduction
In Australia, more than one million tonnes of feedlot manure is produced per annum (Lott *et al*., 1999) from intensive livestock industries. The value of manure as an ameliorant is more than its nutrient benefit alone. As an organic carbon source when applied to a degraded soil, it can significantly improve a soil's physical properties in addition to the chemical fertility. Improvement in infiltration, aggregation and bulk density, can reduce runoff and erosion from wind and water. These changes can also decrease the energy needed for tillage and improve seedling emergence and root penetration.

Eastern Australian feedlots operate in areas of higher rainfall and cropping intensity, but can have a greater magnitude of land degradation. To ameliorate and restore the soils productive capacity, information is required on the potential integration of manure (and/or effluent) and inorganic fertilisers on soil physical properties and soil water relationships in addition to their nutritional properties. As freight costs are often prohibitive for land application of manure great distances from the feedlot, information is also needed on safe application rates as the recommended rate of 25 to 30 t/ha per year is not always possible.

Methods
Site location, instrumentation and soil analysis
Fifteen runoff plots (20 * 5m) which allowed surface and subsurface water and sediment collection were installed on a duplex sandy loam Alfisol, Typic Natrustalf soil (Spodosol, suborder Brown AB) at the CRC Beef feedlot "Tullimba", Northern New South Wales, Australia (30°20'S; 151°12'E). The A_1 horizon was a light grey loam of 0.10 – 0.15 m thickness, containing varying amounts of angular gravel. The A_2 horizon was a very pale, sandy loam to loamy sand, up to 0.3 m thick, usually having more gravel than the surface horizon. The B horizon was yellowish grey clay. Surface soil was acidic (pH_{CaCl2} 4.7 - 5.3) and pH became more alkaline with depth. Organic C, total N and Bray P concentrations are low. Soil bulk density ranged from 1.6 to 1.9 Mg/m^3, and the proportion of exchangeable sodium, especially in the lower slope positions, increased at depth, and exhibited clay dispersion and soil structural breakdown on wetting. Slope varied from 1.8 to 3.8% across the site.

Climate
Rainfall in the region is summer dominant (Oct – Mar) with average annual precipitation of 805 mm. Maximum temperatures generally occur in February, whilst minimum temperatures are below 0^{o}C in July and August generating an average monthly maximum of 15 frosts per month (Green 1993). Humidity is higher throughout the winter months (80 - 85%) and lower in November/December (65%).

Treatments and crop management
Experimental treatments that were applied over three years are summarised in Table 1. The inorganic fertiliser treatment received nutrients based on the estimated nutrient removal from a sorghum crop yielding approximately 20t DM/ha. Treatments were randomised and replicated twice, except for the no manure + effluent treatment. All manure treatments received irrigation in the form of effluent or clean water and the inorganic treatment received clean water only. Effluent shortages meant it was only applied in year 2 and there was no measured response so this allowed the plots designated to receive effluent to be used as additional replicates.

With different manure amounts applied in each year, nomenclatures shown in Table 1 were adopted to describe treatments. Successive crops of forage sorghum (*Sorghum bicolour* cv. Super-Dan) and triticale (*Triticosecale* spp. cv. Madonna) were grown with the seeds broadcast by hand and hand raked into the surface soil for the three year study. Cultivation was minimised being limited to a single light rotary hoeing after manure application, and immediately prior to sowing each crop. Herbicides and insecticides were applied as required.

Table 1. Treatments applied in each of the 3 years of the experiment. Brackets indicate kg N/ha applied as urea.

	No manure	Moderate annual	Moderate annual + N	High Initial + N	Inorganic
			Manure applied (t DM/ha)		
YEAR 1	0 t/ha	20 t/ha	20 t/ha	60 t/ha	Inorganic
YEAR 2	0 t/ha	25 t/ha	25 t/ha+ (120N)	0 t/ha + (180N	Inorganic
YEAR 3	0 t/ha	20 t/ha	20 t/ha+ (120N)	0 t/ha + (170N)	Inorganic

Plant biomass collection and analysis
Sorghum biomass was cut twice and triticale cut once in each year. Harvesting entailed cutting at approximately 80mm above the soil surface, subsampling and weighing, with all biomass removed from the site. Whole top samples were dried at 80^{o}C and ground to <2 mm. Multiple manure samples were taken prior to each land application and subsamples allowed application rate and chemical composition to be determined. Plant and manure samples were digested using the sealed container digest procedure of Anderson and Henderson (1986) for elements other than N. Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES) was used to measure P, K, S, etc. Samples were digested according to Linder and Harley (1942) for nitrogen determination.

Results and Discussion

Biomass produced
Biomass production in a given environment is primarily influenced by nutrients and water supply. Total dry matter yields over three years were higher in manure and inorganic fertiliser treatments cf no manure, however yearly differences between treatments were recorded. Year 1 differences between moderate and high manure application rates may be due to higher mineralization within the high initial single application. No differences between treatments were recorded in year 2. In year 3, +N treatments yielded higher than manure only treatment, generating a 54% increase, up from 37.5% in year 2. Despite the application of fertiliser N to the high initial manure treatment, the triticale in year 3 displayed nitrogen deficiency symptoms. Research in the USA reported organic N mineralization during the second, third and fourth cropping years after initial application was usually about 50, 25 and 12 % of the first year (Midwest Plains Services 1993). Azevedo and Stout (1974) found that nitrogen in most types of manure was only 20-50 % as effective as commercial N fertiliser in increasing short-term crop yield. Hence, supplementing both moderate and high manure application rates with N fertiliser in years following manure application is necessary to avoid N limitation to crop growth.

Plant nutrient removal

Nutrient recovery in the inorganic treatment was higher than manure treatments for N, P, S and Na (Table 3). High dry matter yields and a readily available source of N were responsible for the highest N recovery (63%) in the inorganic treatment. Nitrogen recovery in the manure treatments ranged from 38 to 53% and this was higher than found by Eghball and Power (1999) in a four years study on corn.

Table 2. Annual and 3 year total dry matter yield of forage sorghum and triticale.

	Treatment				
	No manure	Moderate annual	Moderate annual +N	High initial + N	Inorganic
YEAR 1	6784a[A]	10906b	10906b	23187c	23782c
YEAR 2	4117a	18444b	25346b	20247b	17233b
YEAR 3	3320a	10880b	16810c	14060c	16350c
GRAND TOTAL	**14221a**	**40230b**	**53062b**	**57494b**	**57365b**

[A] - Numbers within a row followed by the same letter are not significantly different (P>0.05) according to DMRT.

Phosphorus recovery ranged from 25 to 41 % in the manure treatments as compared to 94 % in the inorganic fertiliser treatment (Table 3). Of the manure treatments plus N, the single large application recovered 11% more P than annual applications potentially due to the longer mineralization period. The supplement of nitrogen made to the split application increased P recovery up to 5%, mainly due to increased yields. In this study, P recovery was much higher than Whalen and Chang (2001) who recovered 5-18 % of applied P manure by irrigated barley. However, their study had lower cropping intensity and poorer climatic conditions. Crops generally removed a much higher quantity of K than that applied, with manure and inorganic treatments exporting > 900 kg K/ha in three years. Recovery of K in the manure treatments ranged from 162 to 269%, whilst inorganic treatment recovery was 172%. Largest K removal was in the inorganic treatment, however the high initial plus N treatment recorded larger K recoveries due to less K applied compared with the inorganic treatment. Removal of whole plant tops highlights the potential export of significant amount of nutrient.

The amount of S removed by the crops ranged from 18 to 29% in the manure treatment and 32 % in the inorganic fertiliser treatment (Table 3). The low recovery of S in the manure treatments was due to a low crop yield and the lack of a balanced N supply. The moderate annual application of manure recovered a lower percentage of the applied S in the crop, as compared to the high initial application made at the start of the experiment. This is likely due to the longer time for the single application to be mineralised. Overall, treatments can be ranked in descending order with respect to % recovery of applied N, P and S as inorganic fertiliser > high initial +N > moderate annual +N > moderate annual manure.

Table 3. Removal of nutrients (kg/ha) by forage sorghum and triticale over 3 years. The percentage of applied nutrient recovered by crops is shown in parentheses.

Nutrient	No manure	Moderate annual	Moderate annual +N	High initial + N	Inorganic
	Total nutrient removed (kg/ha/3 years)				
N	115	337 (38)	505 (45)	588 (53)	765 (63)
P	27	133 (25)	159 (30)	191 (41)	117 (48)
K	306	941 (162)	1153 (217)	1342 (269)	1445 (172)
S	15	46 (18)	59 (24)	65 (29)	76 (32)
Na	5	13 (3)	15 (4)	18 (5)	18 (6)

Hydrology

Lowest cumulative surface runoff and subsurface flow was in the high initial manure treatment and highest cumulative surface runoff was in the control treatment (Figure 1). Many factors control surface runoff, but it seems unlikely that treatment runoff differences could be due to soil cover as manure and inorganic fertiliser crop yield are similar, but the inorganic fertiliser treatment had a higher amount runoff compared to the manure treatments. The difference between the control and the inorganic fertiliser treatment may be partly due to the higher soil cover and root biomass in the inorganic fertiliser treatment. Although the slope varied from 2 to 4% across the experimental area it seems that slope did not have much influence on the amount of runoff from the various treatments. Rainfall intensity did not show a significant correlation with the amount of runoff. The most important factor determining runoff was infiltration capacity. In the third year runoff loss in the inorganic fertiliser treatment was much lower and the infiltration was higher compared to year 2 in this treatment. This was likely due to the decomposition of large masses of roots and stubble. This is supported by King (2001), who reported microbial carbon levels double that of the previous year in this treatment.

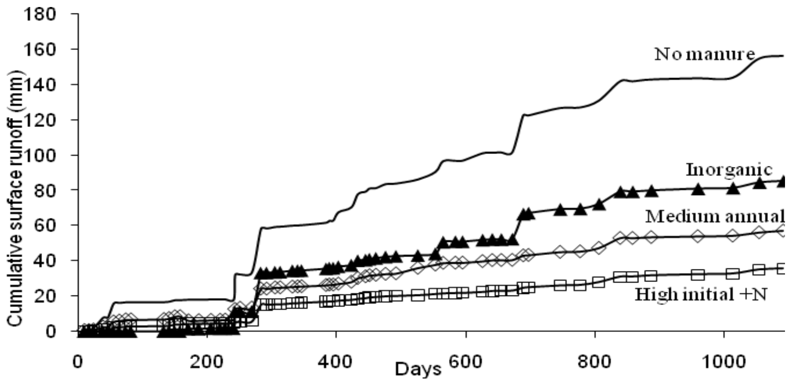

Figure 1. Cumulative surface runoff (mm) over 3 years

Subsurface flow represents a balance between infiltration, soil water retention capacity and rate of water uptake by the crop. There was no difference in cumulative subsurface flow between the control, inorganic and moderate annual manure treatments (mean 150mm loss). The most likely reason for this is that one of the replications of the moderate annual had a high amount of gravel (20%) in the upper surface and the depth to the B horizon was also shallow as compared to the other plots. It is likely that these two factors affected the result. Subsurface loss was lowest from the high initial+N treatment (cumulative 95mm).

Conclusion

The application or manure to land areas completes a natural nutrient recycling process. The nutrient and carbon containing product is commonly applied to land areas designated for crop production. Whilst manure application has been shown to increase crop yields and at high rates is comparable to inorganic fertiliser, nutrients in manure are unbalanced with respect to plant demand. Whether manure is applied at moderate rates annually or a large application is made once over a three year period, inorganic N (and often K depending on soil type) will need to be applied to meet crop demand (especially forage or pasture crops). The application of manure at high rates improves water infiltration as opposed to applying it annually, thus minimising surface and subsurface water flows. It appears a combination of high rates of manure applied once per three or four years and inorganic fertiliser (N), maximises crop yield and recovery of nutrient, whilst minimising water and dissolved nutrient losses.

References

Anderson DL and Henderson LJ (1986) Sealed chamber digestion for plant nutrient analysis. *Agronomy Journal* **78**, 937-938.

Azevedo J, Stout PR (1974) Farm animal manures: an overview of their role in the agricultural environment. California Agric. Exp. St. Ext. Serv. Manual 44. In '*Soils for Management of Organic Wastes and Waste Waters*.' American Society of Agronomy Inc.; Crop Science Society of America Inc.; Soil Science Society of America Inc.

Eghball B, Power JF (1999) Phosphorus and Nitrogen-based Manure and Compost Applications: Corn Production and Soil Phosphorus. *Soil Sci. Soc. Am. J.* **63**, 895-901.

Fischer RA (1985) Number of kernels in wheat crops and the influence of solar radiation and temperature. *Journal of Agricultural Science* **105,** 447-461.

King KL, Hunt JB (2001) Effect of Feedlot Manure and Inorganic Fertilisers on Aspects of soil Biology. In MLA Project 202, Termination Report 1997-2000, University of New England, Armidale.

Linder RC, Harley CP (1942) A rapid method for the determination of nitrogen in plant tissue. *Science* **96**, 565-566.

Lott S, Klepper K, Ahmad R, Blair G, Petrov R (1999) Australia – You're Standing In It. *'Feedlot Waste Management Conference'* Royal Pines Resort, Qld, Aust.

Midwest Plan Service (1985) Midwest Plan Service Livestock Waste Facilities Handbook, MWPS-18, Iowa State University, Ames, Iowa.

Whalen JK, Chang C (2001) Phosphorus accumulation in Cultivated Soils from Long-Term Annual Applications of Cattle Feedlot Manure. *Journal Environmental Quality* **30,** 229-237.