Are differences in soil quality between organic and conventional farming systems greater in more energy-intensive sectors?

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Abstract
The Agricultural Research Group on Sustainability (ARGOS) has undertaken a longitudinal study of primary agricultural production in New Zealand to improve economic, environmental, social and ecological performance of its farms and orchards. As part of these objectives we report on a six year investigation of soil quality between Conventional, Organic and alternative management systems for three production sectors; Sheep and Beef (SB), Dairy (DY) and Kiwifruit (KF). The relative intensity of each sector was ranked according to energy use per unit land area and was the basis of a hypothesis to test whether differences in soil quality increase between management systems with increasing sector intensity.
For each sector, ARGOS established twelve clusters of farms with each cluster consisting of a farm or orchard from each management system matched as well as possible in terms of size, climate, topography and soil type. Properties of one management system constituted a panel. A range of soil measurements were made for each property covering fertility, soil organic matter, biology and physical condition. The quantitative data was analysed using a mixed model fitted with restricted maximum likelihood (REML) whilst qualitative data was analysed using a multinomial regression model run in R. Ten of the 24 soil properties measured (pH, exch-Ca, BS%, mineralisable-N, soil bulk density, moisture content, porosity, aggregation and earthworm numbers and weights) had statistically significant interactions that supported our premise that differences in soil quality between Conventional and Organic increased with land-use intensity. These differences reached their maximums in the KF panels, our most intensively managed sector in terms of energy use per unit area. A majority, however, of soil properties had significant management effects but not all were supportive of Organic, and were often minor compared to differences between panels.
Integrated was the most sustainable and best performed system in the SB panel and had better soil quality, due to the modest amounts of fertiliser used to improve production, and lower total energy costs per weight of product. Some improvements in soil quality were found in the DY panel under Organic management but many panel members are still in a transitional stage and further effects may still follow. KF had the worst soil quality overall but a large part of this can be attributed to running a modern commercial orcharding system. Adopting Organic management practice in KF orchards, however, improved soil quality.

Key Words
Organic, earthworms, soil property, ARGOS, pasture, kiwifruit.

Introduction
The New Zealand Agriculture Research Group On Sustainability (ARGOS) is seeking to identify pathways to improve sustainability for New Zealand agriculture through improving economic, environmental, social and ecological performance. Of the 14.7 million ha of farming land in NZ, about 8 million ha is grassland, of which ~5.8 million ha is used for Sheep & Beef grazing (SB) and ~1.9 million ha is used for dairying (DY). Kiwifruit horticulture (KF), although only occupying around 14,000 ha in total, is a relatively intensive industry producing high volumes of fruit per unit area (100 million trays annually; ~20 tonnes/ha).
Our inquiry is whether differences in soil quality between Organic and Conventional management systems (and two other alternative systems) increase with the intensity of the production sector. We began with a simple null hypothesis i.e. that there are no differences in soil quality between management systems for the three sectors. We report on a number of key soil fertility, biological and physical indices.

Methods

Program structure

The ARGOS program concentrated on establishing 12 groups (clusters) of commercial farms or orchards for each sector that were under the target management systems and in close proximity. Each SB cluster consisted of an Organic farm with a matched Integrated and Conventional counterpart. Each DY cluster consists of an Organic farm matched with a Conventional counterpart. Kiwifruit clusters were selected from three groups; (i) conventionally managed 'Hayward' (Green) (*Actinidia deliciosa*), (ii) organically managed 'Hayward' (Organic), and (iii) conventionally managed 'Hort 16A' (Gold) (*Actinidia chinensis*). The sector farms or orchards that made up a management regime constituted a panel.

Structures used for comparison were:

1. between production sector (i.e. SB, DY or KF)
2. between management system (i.e. Organic, Integrated/Gold or Conventional)
3. between landform or sampling position (i.e. SB & DY- flat, slope or crest; KF- within row (vines) or between row (alleyway)).

Management system

By definition, Organic farms use accredited organic production protocols and have achieved organic accreditation status. Integrated farms follow industry protocols that although not to organic status, may require reduced pesticide and herbicide use, higher environmental performance and/or animal welfare standards and usually have higher production. Conventional farms represent the *status quo*. By virtue of the aforementioned clusters and management systems, each sector is ostensibly represented by 24-36 farms or orchards barring withdrawal of properties from the study through circumstance.

Measurements

A range of soil physical, fertility and biological measurements were made for each farm or orchard using qualitative and quantitative methods. Soil physical measurements included soil porosity and aggregation (by visual soil assessment; (Shepherd 2000), soil bulk density (SBD) and soil moisture content (SMC; at field capacity). Soil chemical analyses included pH, Olsen-P, resin-P, sulphate-S, organic-S, exchangeable cations, potentially mineralisable-N, organic-C, total-N, cation exchange capacity (CEC) and P retention capacity. Soil biology measurements included 0.5 M K_2SO_4-soluble C, soil microbial biomass (SMB) C and N and basal respiration.

Statistical analysis

The quantitative data was analysed using a mixed model fitted with restricted maximum likelihood (REML). This method allowed analysis of the entire data-set simultaneously, even though the data was not balanced and there were several areas where data was not available for many variables. Qualitative data was analysed using a multinomial regression model run in R. Principal components analysis (PCA) of all major soil properties was also conducted.

Energy usage

Comprehensive energy usage values were complied for each and used to determine a set of energy intensity indicators per hectare or per kg product and included fuel and electricity plus the embodied energy in fertiliser, agrichemicals and capital items (Barber and Lucock 2006; Barber and Benge 2006; Barber, Pellow *et al.* 2008).

Results

Energy use

Sector energy use values increased by an order of magnitude from SB<<DY<KF on a unit area basis but the order changed to KF<<SB<DY when calculated on a unit weight basis (of product leaving the farm or orchard) (Table 1). Within each sector there was a general decrease in energy use per unit area from Conventional to Organic panels but energy usage for KF-Gold and SB-Integrated panels was best in terms of efficiency for product produced for their respective sectors Table 1.

Soil fertility

Olsen-P and sulphate values were lowest for the SB sector overall but both KF Conventional and DY Gold panels had P values that were above recommended optimum ranges for NZ pastures (20-40) (Roberts, Morton *et al.* 1999). P and S values for SB Organic were below recommended critical ranges (P 20-30; S 10-

12) for NZ pastures (Morton, Roberts *et al.* 1994). Soil pH, CEC, cation and total base saturation (BS) values were highest overall for DY and KF sectors and lowest for SB. Organic panels generally had significantly higher cation values than the other panels although SB Organic showed a reverse trend for Ca and K values. Aside from soil-based sector differences, soil organic matter (SOM) values were generally higher for Organic panels but only KF specifically. C/N ratios were significantly higher for KF than either DY and SB but within all sectors, Organic panel C/N ratios were consistently greater than Conventional or Integrated/Gold. Organic-S, expressed gravimetrically (soil weight) was only significantly different at the sector level and highest for DY but expressed on a soil carbon basis only panel effects were significant whereupon Organic values were consistently lower than either Conventional and/or Integrated/Gold. Organic. Potentially (anaerobic) mineralisable-N (AMN) values were significantly greater ($P<0.001$) for the DY and SB sectors compared with KF, but values were also consistently greater for the Organic panels.

Soil biology

Earthworm numbers and weights ranged by an order of magnitude from KY<<SB=DY. A strong sector interaction ($P<0.01$) showed that differences in numbers were highly significant between the DY and KF panels but not SB. There was no significant increase in earthworm weights between DY panels.
Soil microbial biomass and basal respiration values increased significantly from KF<<DY=SB but values for Organic panels were also higher ($0.05<P<0.001$) compared with Conventional. These differences tended to decrease when related to soil-C or –N content.

Soil physical condition

VSA scores for soil porosity (Figure 2) and soil aggregation showed that generally, soil structure significantly deteriorated from SB>DY>KY. Scores for "excellent" porosity were clearly fewer for KY, with only ~15% in this category compared with more than 60% overall for SB. Porosity scores for "good" dominated the distribution for DY (~55%). Scores for soil aggregation followed similar trends.
Differences in soil porosity between panels were only significant for KY with Organic scoring almost twice as many excellent scores as Conventional and Gold, and far fewer fair and poor scores (Figure 2). KY Organic also had significantly more good scores and hence, far fewer fair and poor scores.

Table 1. Sector energy use and stocking rates for the differing panels.

Term	Sheep and Beef [1]			Dairy [2]		Kiwifruit [3]		
	Conv.	Integ.	Org.	Conv.	Org.	Conv.	Gold	Org.
MJ/ha	3416	4130	2332	37725	26311	56627	55062	40362
MJ/kg	9.2	7.5	9.5	38	38	2.2	1.7	2.0
SU [4]/ha	10.7	12.5	10.1	12.9	9.3	n/a	n/a	n/a
Fertiliser [5] kg/ha/y	60	84	13	214	113	534	517	388

[1] MJ/kg includes both meat or wool leaving farm (1Kg=~8.5 MJ); [2] 1kg MS contains ~38 MJ of energy; [3] 1 tray contains 6.0-7.0 (gold) or 6.7-7.7 (green) MJ; [4] Stocking rate- stock units/ha; [5] total annual fertiliser use (N, P, S, K).

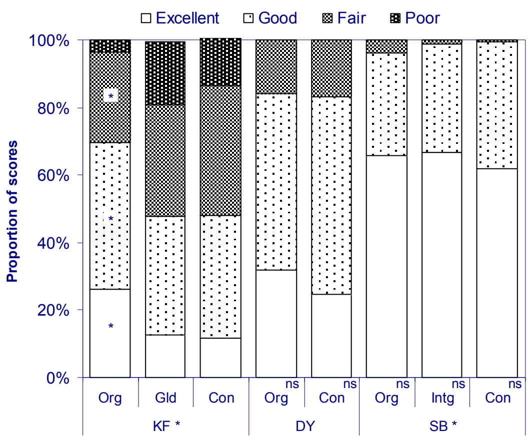

Figure 2. Soil porosity score distribution for each panel for KF, DY and SB sectors. An asterisk denotes a significant difference in scores at an individual level or cross-sector basis (ns; not significant).

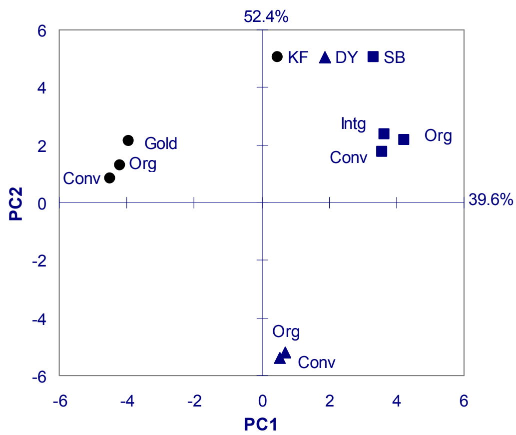

Figure 3. Principal components analysis of 27 mean soil indice values for SB, DY and KF sectors.

Principal components analysis
PCA showed distinct differences between management systems, KF in particular, but these were generally found to be minor compared to differences between the production sectors (Figure 2). The x (PC1) and y (PC2) axes accounted for 52% and 40%, respectively, of the total variation. Loadings for the PC1 component were largely predicated around those for soil fertility and physical condition (pH, CEC, Olsen-P, exch-Ca, aggregation, porosity, SBD and SMC) whilst loadings for the PC2 component were almost all predicated around soil organic matter and microbial biomass (AMN, N%, C%, C/N ratio, MC/MN ratio and SMB-N).

Conclusions
Of the 24 or so soil properties measured, ten (pH, exch-Ca, BS%, AMN, SBD, SMC, porosity, aggregation and earthworm numbers and weights) had interactions that supported our premise that differences in soil quality between Conventional and Organic increased with land-use intensity. These differences reached their maximums in KF, our most intensively managed sector in terms of energy use per unit area. Although some similar trends were also noted in the DY sector, many Organic farms in this panel are still in a formative stage and may have not reached equilibrium with their new management regime. A majority, of soil properties however, had significant management differences and many were supportive of Organic panels and higher soil quality but many were also often minor (<10%) compared to differences between production sectors related to soil geomorphology and land-use. Sparling and Schipper (2002) reported in their NZ study of land-use and soil quality that many soil properties have a basis in the soil's geomorphology and land-use and management will have a variable effect on these. Whilst we can not be entirely sure about the magnitude of the effects from differences in soil properties, they appear generally minor.
For KF, Gold was the most efficiently produced kiwifruit (MJ/kg), mainly due to its vigour, and Organic was second whilst DY Organic was also more energy efficient (MJ/kg MS) than DY Conventional. Integrated was the most sustainable and best performed system in SB and had better soil quality, due to the modest amounts of fertiliser used to improve production, and lower total energy costs per weight of product. Only a few improvements in soil quality (lower Olsen-P, higher SMB-C and earthworm numbers) were found for DY under Organic management but many Organic panel members are still in a transitional stage and further effects may still follow. Although KF had the worst soil quality of the three sectors, a large part of this could be attributed to running a modern commercial orcharding system. Adopting Organic management practice in KF orchards, however, improved soil quality.

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