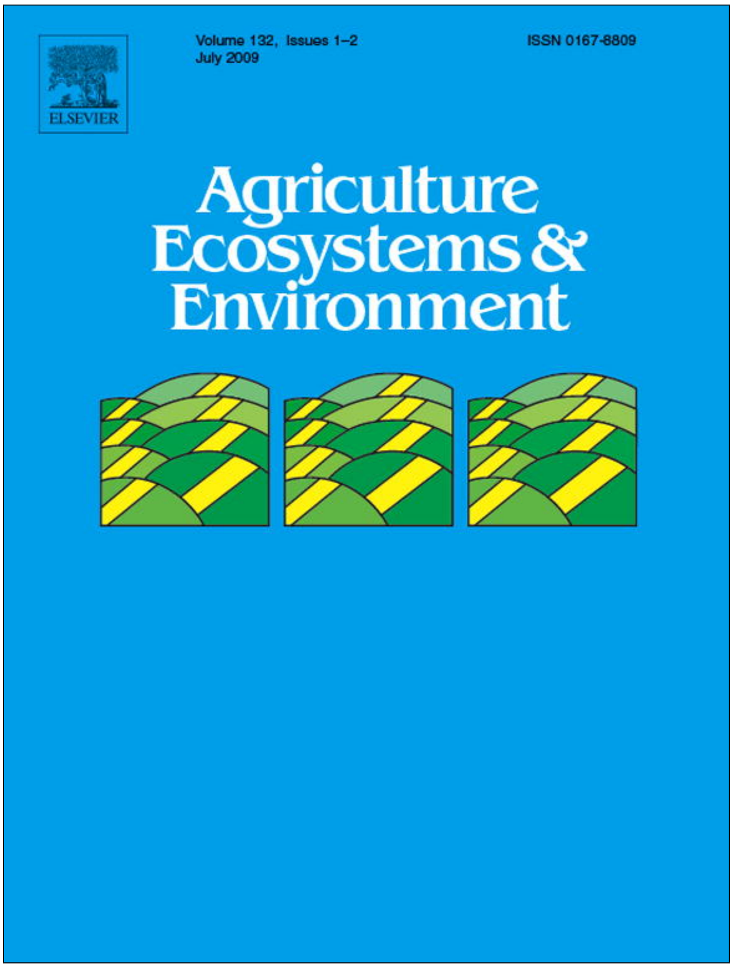
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Comparison of soil quality and nutrient budgets between organic and conventional kiwifruit orchards

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ABSTRACT

Three long-term (>10 years) systems of kiwifruit production were compared at 36 sites with respect to simple input/output nutrient budgets, extractable soil nutrient levels, soil organic matter status, the size and activity of the soil microbial biomass, earthworm numbers and key soil physical properties. These systems were (i) conventional production of the green-fleshed variety 'Hayward' (Green), (ii) organic production of 'Hayward' (Organic) and (iii) conventional production of the yellow/gold-fleshed variety 'Hort 16A' (Gold). Crop yields and nutrient removals were least for Organic and greatest for Gold, with Green being intermediate. The major nutrients removed in the harvested crop were K and N. Simple input/output nutrient budgets showed that inputs greatly exceeded removals in the harvested crop for all nutrients considered (i.e. N, P, S, K, Mg, Ca) in all three systems, suggesting nutrient inputs could be reduced. Soil organic C and total N content were greater under Organic and Gold than Green whilst extractable P was least under Organic. Soluble C, basal respiration and metabolic quotient were unaffected by production system whilst microbial biomass C and N were greatest under Organic. Within systems, organic C, total N, microbial biomass C and N and mineralisable N were greater between plant rows than below the vine canopies whilst the reverse was the case for metabolic quotient and extractable P. Soil bulk density was least and water content at field capacity and earthworm numbers were greatest under the organic systems. It was concluded that long-term soil fertility can be maintained adequately under organic management and added benefits are increased organic matter content, a larger microbial biomass and improved soil physical condition. Although Organic orchards generally produce less fruit than their Green counterparts, mainly because of fertiliser differences and the absence of synthetic growth regulators, comparatively good returns and surpluses can still be achieved.

1. Introduction

There is an increasing worldwide requirement for agricultural and horticultural produce not only to meet high standards of quality but also to be produced using environmentally sound practices. To this end, principles of sustainability and resilience have an increasingly important part to play in the drafting of economically viable production protocols. The increasing interest in organic production systems is in response to notions that they are inherently more sustainable (Condron et al., 2000) although evidence for this is scarce. The market premiums that organic produce can earn over their conventional counterparts can ensure economic viability in the face of generally lower overall production (Pacini et al., 2003; Reganold et al., 1993; Springett et al., 1994).

The New Zealand Agriculture Research Group on Sustainability (ARGOS) is seeking to identify pathways to improve sustainability for New Zealand agriculture. To this end, ARGOS is studying and comparing the economic, social and environmental consequences of differing farming systems. An important first question for ARGOS is whether certified organic systems do, in fact, perform differently from their conventional counterparts. Kiwifruit orchards are a small scale, highly intense system which represents an important export industry for New Zealand. Kiwifruit orchards are a woody and complex ecological landscape supporting a highly intensive form of agriculture, which contrast greatly with the other types of broad-acre livestock farming systems that ARGOS is studying. A major part of any comparison of resilience between production systems includes soil quality and whether commercially intensive systems are more damaging to soil's fertility and biological function than an arguably more "natural" organic system.

In this study, three long-term (>10 years) kiwifruit (*Actinidia* spp.) systems are compared. These are (i) conventional

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production of the green-fleshed variety, 'Hayward', (ii) organic production of 'Hayward' and (iii) conventional production of the newer, golden-fleshed kiwifruit variety, 'Hort 16A'. The comparison included simple input/output nutrient budgets, extractable soil nutrient levels, soil physical properties, size and activity of the soil microbial biomass and earthworm numbers.

2. Materials and methods

2.1. Site selection

Thirty-six orchards were selected and evenly divided between three groups: (i) conventionally managed 'Hayward' (*Actinidia deliciosa*), (ii) organically managed 'Hayward', and (iii) conventionally managed 'Hort 16A' (*Actinidia chinensis*). Conventional management follows a crop protection programme called "Kiwi-Green" prescribed by the export company ZESPRI International Ltd. which provides a single point of entry into markets. It is based on integrated management principles and has emphasis on minimizing chemical use on orchards. Fruit exports are also governed by international GlobalGap regulations for production. Organic management precludes the use of synthetic fertiliser and crop protection chemicals in compliance with BioGro New Zealand Ltd. certification standards and relies on biological pest and disease control measures, mechanical cultivation, mineral-bearing rocks, crop residues, animal manures, composts and organic extracts.

One orchard from each group was allocated to each of the 12 clusters matched according to location (60% within 1 km, none more than 3 km distant), soil type, topography and climate as closely as possible. Every cluster, therefore, contained three orchards designated as 'Green', 'Organic' or 'Gold', respectively. Organic orchards had been certified organic for an average of 12 years although most of the orchards were conventional previously for at least 10 years. The majority of clusters (10) were located in the Bay of Plenty region of New Zealand where about 80% of the total crop area is grown. One cluster each was located in Kerikeri (Northland) and Motueka (Nelson). Outside Bay of Plenty, these are two of the biggest kiwifruit growing regions with each growing about 5% of the total area (Fig. 1).

2.2. Soil classification

The 10 clusters situated in the Te Puke area of the Bay of Plenty region are all classified as being on Allophanic Orthic Pumice soils (Hewitt, 1993) (USDA Andisols - Vitrands/Vitricryands; FAO Mollic Andosol) having formed predominantly from ryolitic tephra between 4000 and 40,000 years ago during the region's geologic history of periodic volcanic eruptions (Molloy, 1988). The remaining clusters in Keri Keri and Motueka are on Brown Clay loams (USDA Oxisol-Udox; FAO Orthic Ferrasol) and stony Orthic Brown soils (USDA Inceptisol - Dystrocryepts; FAO Umbric Cambisol) (Cutler, 1968), respectively.

2.3. Soil sampling and analysis

To account for any spatial variability in soil quality, samples (0–15 cm) were taken from three separate kiwifruit blocks (or management units) on each orchard. Within each block, there were three randomly located soil monitoring sites (SMS), each in the size of two adjacent kiwifruit bays, from which all samples were collected. Sampling at each monitoring site occurred at two sampling positions, i.e. under the leaders of vines (within rows, WR) and in the areas between-the-rows (BR). Sampling occurred at winter of both 2004 and 2006, prior to annual fertiliser and/or manure applications, and consisted of ten 150 mm deep, 25 mm diameter cores for each SMS.

Qualitative visual soil assessments (VSA) (Shepherd, 2000) were made in the field for soil porosity and aggregation and were scored 1–4, 1 being the best. Quantitative measurements were made for soil bulk density (Grossman and Reinsch, 1994), water holding capacity (i.e. soil water content at field capacity) and earthworm populations (Fraser et al., 1996). Soil texture was measured for each SMS for each management unit using the classical hand rolled-ball technique. Soil chemical analyses including 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 (Blakemore et al., 1987), were made on composite samples collected from each block (i.e. samples from the three monitoring sites within each block were aggregated). Measurements of soil biological activity used

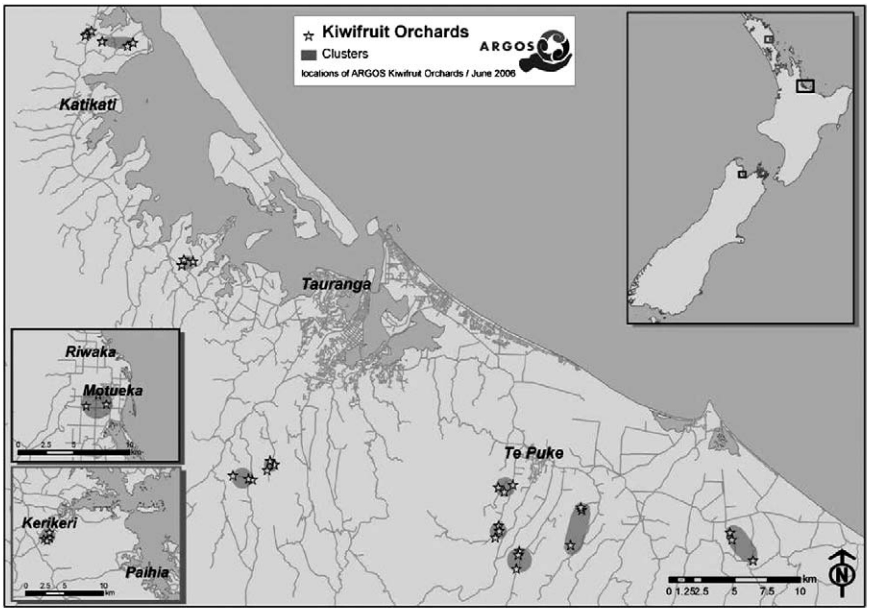

Fig. 1. Location and distribution of the 12 kiwifruit clusters each containing one Green, Gold and Organic orchard.

the same composite samples collected for the chemical tests and sieved through a 4 mm mesh and kept at 1 °C until analyzed. Measurements made included 0.5 M K_2SO_4-soluble C (Matlou and Haynes, 2006), microbial biomass C and N (Jorgenson, 1995a,b) and basal respiration (Kelliher et al., 2005). Metabolic quotient, the ratio of respiration rate to microbial biomass (a useful indicator of the efficiency of the microbial population) was also calculated.

2.4. Nutrient budgets

Simple nutrient budgets were estimated for each group based on exports in fruit (i.e. yields) and mean fruit macronutrient composition from published reports for Green, Organic and Gold fruit, whilst external inputs were calculated based on growers records. These inputs included nutrients in inorganic manufactured fertilisers, soil amendments (e.g. lime), reactive phosphate rock, composts, manures, and liquid organic preparations (e.g. compost teas). Internal inputs calculated (recycled returns to the orchard floor) included those from leaf litter fall and returned prunings (and their mean nutrient composition) but returns from mowing of the grass sward in the inter-row area were not included.

2.5. Statistical analysis

Chemical and biological soil test values were compared by analysis of variance (ANOVA) conducted using Genstat version 8.0 (VSN International Ltd., 2008). Means and least significant differences at the 5% level (LSD, $P < 0.05$) are given for data that is normally distributed. Data on earthworm numbers were log-transformed before ANOVA. Analysis was hierarchical in design and conducted according to *cluster/system/sampling position.*

Analysis of scores for soil porosity and aggregation was based on the frequency distribution of scores. Analysis was by both a multinomial linear regression model and a generalised linear mixed model (GLMM) with a binomial distribution and prediction of 95% confidence intervals using a similar hierarchical structure as described above. For purposes of interpretation the scores from 1 to 4 were assigned descriptions from excellent-to-poor, respectively.

3. Results

3.1. Site and soils characterization

The Te Puke region, where 10 of the clusters were based, has average annual air and soil temperatures and rainfall of 14.0 °C, 14.3 °C and 1720 mm, respectively, a little lower than that for the Keri Keri region cluster (15.2 °C, 15.2 °C and 1750 mm, respectively). The Motueka cluster, being considerably further south, has significantly lower average annual air and soil temperatures but also lower annual rainfall (12.5 °C, 11.5 °C and 1420 mm, respectively).

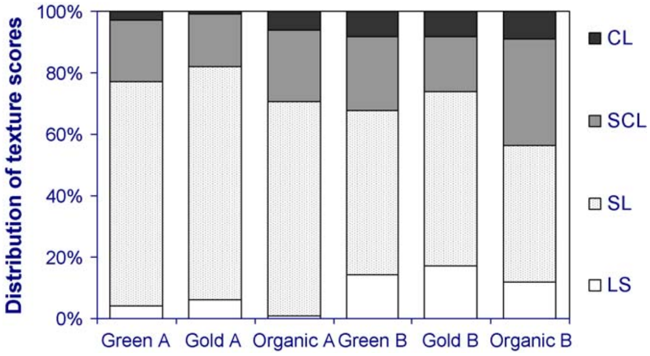

Fig. 2. Distribution of texture scores for A and B horizons for Green, Gold and Organic kiwifruit orchards (LS = loamy sand; SL = sandy loam; SCL = sandy–clay loam; CL = clay loam).

Approximately 90% of soil textures for the upper horizons (A) of all orchards were found to be either sandy or sandy–clay loams (Fig. 2). The lower horizons (B) were, on average, a little coarser with more soils classed as loamy sands. No significant differences were found in the distribution of the soil texture classifications between management systems. The average depth of the A horizon to the B horizon was 20–23 cm across all orchards but this varied considerably (CV% 39–51). The ranges of depth values for each management system, however, were not significantly different.

3.2. Nutrient budgets

Average production (2004–2006) varied considerably from approximately 5700 trays ha^{-1} ($\sim$20 T ha^{-1}) for Organic, to over 9000 trays ha^{-1} for Gold ($\sim$32 T ha^{-1}) (Table 1). Part of this difference stemmed from fruit size, which was 6% and 11% higher for Green and Gold fruit, respectively, over the period (Zespri International, 2008). As a consequence, the amounts of nutrients exported from the orchard in fruit were greatest for Gold and least for Organic. The main macronutrients removed in fruit were K ($\sim$52–97 kg ha^{-1}) and N ($\sim$27–48 kg ha^{-1}), but only small amounts ($<$10 kg ha^{-1}) of P, S, Ca and Mg were removed.

Table 1

Calculated mean production and nutrient outputs, and organic additions and nutrient inputs, for conventional Hayward (Green), organic Hayward (Organic) and conventional Hort 16A (Gold) kiwifruit systems.

	Outputs[a]			Inputs[b,c]						
	Green	Organic	Gold	Type	Green		Organic kg ha^{-1}		Gold	
				Compost	100		5900		200	
				Fish[d]	0		1900		0	
Production (trays/ha)	7500	5700	9300	Manure	600		0		1000	
		kg ha^{-1}			*E*	*I*	*E*	*I*	*E*	*I*
Nitrogen	35	27	48		120	80	60	60	120	100
Phosphorus	7	5	9		40	10	50	10	50	10
Sulphur	7	5	8		110	10	60	10	120	20
Potassium	68	52	97		210	60	120	40	230	70
Magnesium	3	2	4		50	10	20	10	80	20
Calcium	5	4	7		300	80	170	60	290	100

[a] Fruit outputs calculated using average fruit mineral concentrations for Green and Organic (Benge et al., 2000), and for Hort 16A (Boyd, 2005).

[b] External inputs (E) from fertilisers, composts etc (Benge, 2006).

[c] Internal inputs (I) estimated from the return of prunings and leaf fall (Clark and Smith, 1988; Ferguson and Eiseman, 1983).

[d] Fish applied as L ha^{-1}.

Table 2

Soil chemical property values (0–15 cm) from conventional Hayward (Green), organic Hayward (Organic) and conventional Hort 16A (Gold) kiwifruit systems.

System	Sampling position	Olsen-P (mg P kg−1 soil)	Resin-P (mg P kg−1 soil)	P retention (ASC%)	Sulphate S (mg S kg−1 soil)	Organic S (mg S kg−1 soil)	Organic C (w/w %)	Total N	C/N ratio	Mineralisable N (g kg−1 soil N)	pH	CEC	Ca (cmol kg−1 soil)	Mg (cmol kg−1 soil)	K (cmol kg−1 soil)	Na (cmol kg−1 soil)
Green	WR	55.5	118	63.0	19.0	6.3	4.9	0.41	12.1	21.6	6.5	17.0	10.8	1.8	0.7	0.10
	BR	40.8	90	62.7	16.8	6.6	5.4	0.45	12.0	25.7	6.5	18.2	12.4	2.0	0.7	0.09
	Mean	48.1 ab	104 ab	62.8 a	17.9 ab	6.5 a	5.1 a	0.43 a	12.1 ab	23.7 ab	6.5 b	17.6 a	11.6 a	1.9 a	0.7 a	0.09 a
	Range	17–111	40–204	17–96	2–113	1–14	2–9	0.2–0.8	10–15	10–108	5.9-7.2	9–28	6–24	0.9–3.2	0.3–1.7	0.0–0.3
	CV%	40%	41%	36%	91%	54%	26%	28%	8%	65%	4%	22%	30%	28%	37%	28%
Organic	WR	50.3	108	65.2	14.0	7.1	5.5	0.45	12.3	26.3	6.6	19.7	14.0	2.4	0.8	0.11
	BR	37.1	82	65.8	15.0	7.3	5.8	0.49	12.0	27.8	6.8	19.4	13.1	2.1	0.8	0.10
	Mean	43.7 a	95 a	65.5 a	14.5 a	7.2 a	5.7 b	0.47 b	12.1 b	27.0 b	6.7 c	19.5 b	13.6 b	2.3 b	0.8 a	0.11 a
	Range	11–159	24–346	23–94	2–63	1–13	3–8	0.2–0.7	10–16	11–81	6.1–7.2	13–30	7–22	1.2–4.3	0.3–1.4	0.1–0.2
	CV%	50%	56%	32%	78%	43%	21%	23%	8%	51%	3%	20%	24%	30%	28%	25%
Gold	WR	65.6	147	64.2	21.2	8.6	5.3	0.45	11.9	21.5	6.2	17.7	10.1	1.9	0.7	0.13
	BR	50.0	120	65.6	18.9	8.7	5.9	0.50	11.9	23.5	6.5	19.4	12.6	2.1	0.8	0.11
	Mean	57.8 b	134 b	64.9 a	20.1 b	8.7 b	5.6 b	0.47 b	11.9 a	22.5 a	6.4 a	18.6 ab	11.4 a	2.0 ab	0.7 a	0.12 a
	Range	14–217	24–414	18–97	1–105	2–17	1–10	0.1–0.8	10–15	11–81	5.4–7.1	9–36	3–29	0.6–3.8	0.3–1.7	0.1–0.4
	CV%	51%	51%	33%	78%	47%	26%	27%	9%	48%	5%	28%	42%	33%	32%	53%
Significance	System	*	*	ns	*	**	*	*	*	***	***	**	***	*	ns	ns
	Landform	***	***	ns	ns	ns	***	***	**	***	ns	***	***	ns	**	**
	System × land form	**	ns	ns	ns	ns	ns	ns	ns	ns	***	***	***	***	***	ns
LSD (5%)	11.6	33	5.0	4.8	1.4	0.38	0.03	0.2	2.6	0.1	1.2	1.3	0.3	0.09	0.02	
LSD system[a]	5.9	11	1.0	2.6	0.4	0.21	0.02	0.21	2.4	0.1	0.7	0.8	0.1	0.05	0.01	

ANOVA level of statistical significance; ns- not significant, *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

[a] LSD: least significant difference ($P < 0.05$) for the same level of system. Means followed by the same letter are not significantly different according to Duncan's multiple range test ($P < 0.05$).

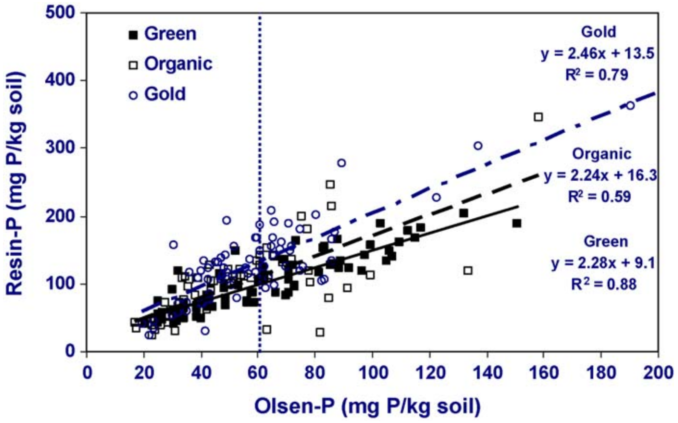

Fig. 3. Relationship between resin-P and Olsen-P in soils from conventional Hayward (Green), organic Hayward (Organic) and conventional Hort 16A (Gold) kiwifruit systems. Linear regression equations and correlation coefficients shown with dotted vertical line denoting upper guideline Olsen-P value.

For all nutrients, inputs exceeded outputs in fruit by considerable margins (Table 1). Most external nutrient inputs were similar for the two conventional systems but N, K, S, Ca and Mg inputs were about 50% lower for Organic. Nitrogen in particular, was applied almost solely in Organic orchards by way of organic inputs, mainly in composts and fish waste preparations. Although organic material is also applied in a number of the Green and Gold orchards, approximately 5 times more was applied on average to Organic orchards. Manure and compost were the main forms of organic matter applied to Green and Gold orchards although applications were only occasional, and to just two or three orchards. Manure was not applied separately in Organic orchards (Table 1). The amounts of nutrients recycled internally by the return of prunings to the orchard floor differed between systems (Gold > Green > Organic) and were substantial for N, K and Ca (Table 1).

3.3. Soil fertility

Both Olsen-P and resin-P values were significantly lower for Organic than Gold with Green having intermediate values (Table 2). Regression relationships between resin-P and Olsen-P (Fig. 3) were similar for the three land uses and were not significantly different between the Organic and the two conventional systems. P retention capacity was unaffected by system. Sulphate S was least for Organic and greatest for Gold. Organic S was significantly greater under Gold than Green or Organic whilst mineralisable N was least for Gold and greatest for Organic. Organic C and total N were greater for Organic and Gold than for Green whilst the C/N ratio was lowest for Gold and highest for Organic. CEC (measured by ammonium acetate ph 7; Blakemore et al., 1987) was greatest for Organic, intermediate for Gold and lowest for Green. Soil pH was significantly higher for Organic than Green and Gold (6.7 vs. 6.5 and 6.4, respectively) although differences were relatively small (Table 2). Sampling position also affected values with these significantly lower for Green and Gold WR. Extractable Ca and Mg were greatest for Organic.

There were significant differences in soil chemical properties due to sampling position (Table 2). Olsen-P and resin-P were greater within rows (WR) for all systems whilst organic C, total N, mineralisable N and CEC were greater between rows (BR). For extractable Ca, Mg and K, values were greater BR for Green and Gold but tended to be greater WR for Organic.

3.4. Soil physical condition

Soil bulk density was greatest under Green and least under Organic whilst the reverse was the case for WHC at field capacity (Table 3). Although VSA porosity (and aggregation) scores were

Table 3

Bulk density, water holding capacity at field capacity (WHC), the size and activity of the microbial biomass and earthworm numbers in soils (0–15 cm) from conventional Hayward (Green), organic Hayward (Organic) and conventional Hort 16A (Gold) kiwifruit systems.

System	Sampling position	Bulk density ($g\ cm^{-3}$)	WHC ($g\ cm^{-3}$)	Soluble C ($mg\ C\ kg^{-1}$)	Microbial biomass-C ($mg\ C\ kg^{-1}$)	Microbial biomass-N ($mg\ N\ kg^{-1}$)	Basal respiration ($mg\ CO_2\ kg^{-1}$ soil day^{-1})	Metabolic quotient ($mg\ CO_2\ g^{-1}$ MBC day^{-1})	Earthworms ($No.\ m^{-2}$)[a]
Green	WR	0.83	0.50	133	287	53	19.2	60.0	51
	BR	0.82	0.51	144	424	76	20.6	46.2	106
	Mean	0.82 c	0.50 a	138 a	356 a	65 a	19.9 a	53.1 a	74 a
	Range	0.6–1.2	0.3–0.7	34-360	20–1042	109–222	4–69	11–164	0–659
	CV%	26%	28%	56%	51%	57%	54%	57%	100%
Organic	WR	0.75	0.62	143	387	88	22.3	54.6	119
	BR	0.76	0.57	148	468	99	22.3	41.9	149
	Mean	0.75 a	0.59 b	146 a	427 b	93 b	22.3 a	48.2 a	133 b
	Range	0.6–1.1	0.3–1.0	35–335	31–1152	136–155	7–42	10–92	0–504
	CV%	21%	23%	53%	40%	38%	30%	42%	71%
Gold	WR	0.79	0.55	151	329	64	19.4	57.9	61
	BR	0.78	0.55	157	439	86	20.0	42.9	87
	Mean	0.78 b	0.55 b	154 a	384 ab	75 a	19.7 a	50.4 a	73 a
	Range	0.6–1.3	0.2–1.2	38–356	15–997	137–200	6–44	8-169	0-674
	CV%	27%	28%	54%	44%	51%	42%	59%	119%
Significance	System	**	***	ns	**	***	ns	ns	*
	Landform	ns	ns	*	***	***	ns	***	***
	System × landform	ns	ns	ns	ns	ns	ns	ns	**
LSD (5%)	0.03	0.05	19	46	18	6.1	17.4	50	
[b]LSD system	0.04	0.02	18	45	12	2.4	7.1	20	

ANOVA level of statistical significance; ns- not significant, $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$. Means followed by the same letter are not significantly different according to Duncan's multiple range test ($P < 0.05$).

[a] Geometric means and maximum LSD presented.

[b] LSD: least significant difference ($P < 0.05$) for the same level of system.

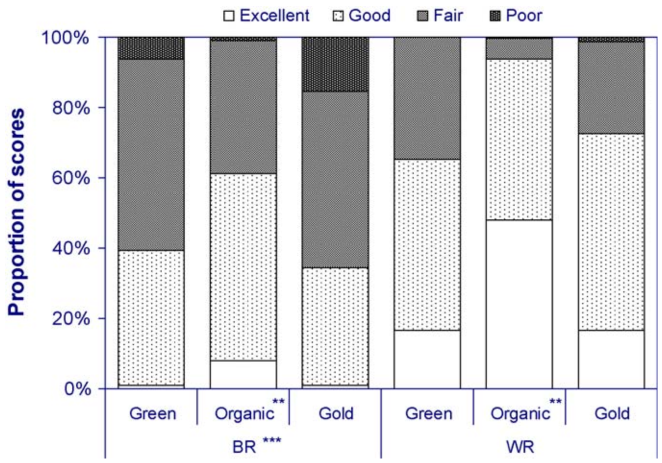

Fig. 4. Summary of mean visual soil assessment (VSA) scores for porosity in soils from conventional Hayward (Green), organic Hayward (Organic) and conventional Hort 16A (Gold) kiwifruit systems. (Level of significance for system or sampling position shown in figure; ns -not significant, $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$).

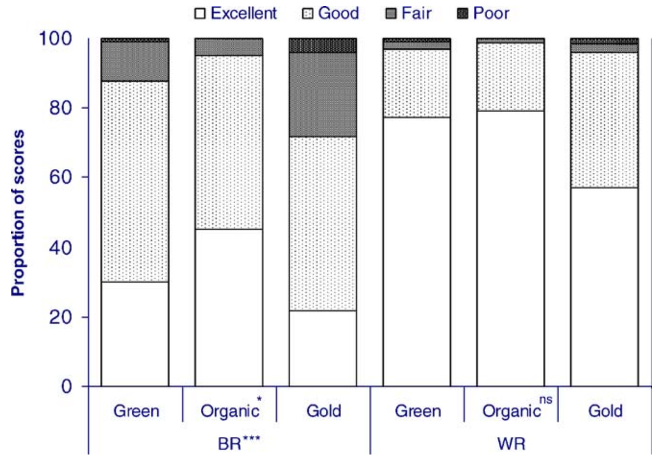

Fig. 5. Summary of mean visual soil assessment (VSA) scores for aggregation in soils from conventional Hayward (Green), organic Hayward (Organic) and conventional Hort 16A (Gold) kiwifruit systems. (Level of significance for system or sampling position shown in figure; ns -not significant, $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$).

highly variable, there was a clear and significant trend for a greater number of excellent and good porosity scores for Organic compared to Green and Gold with a significantly ($P < 0.01$) more positive overall distribution of scores (Fig. 4). Similarly, the distribution of aggregation scores proved more positive overall for Organic (Fig. 5) although scoring trends were less decisive WR. Scoring for both porosity and aggregation was much more decisive for sampling position where scores for BR were considerably less favorable (i.e. much greater proportion of fair and good) ($P < 0.001$) than those for WR for all systems.

3.5. *Soil biology*

Microbial biomass C and N were greater under Organic than Green or Gold but there were no significant differences between systems for soluble C (Table 3). Respiration rate and metabolic quotient were also unaffected by system whilst earthworm numbers were substantially greater under Organic than under the conventional Green and Gold systems.

Microbial biomass C and N and earthworm numbers were higher for all systems BR than WR but the reverse was the case for the metabolic quotient (Table 3). Respiration rate was unaffected by sampling position.

3.6. *Profitability*

The average operating surpluses resulting from the production levels presented here were approximately NZ$13,000/ha, NZ$17,000/ha and NZ$28,000/ha for Green, Organic and Gold, respectively. The higher return for Organic is the result of higher per tray returns and lower operating expenditure. The significantly higher tray numbers for Gold, however, has resulted in a much higher bottom line.

4. Discussion

4.1. *Production, nutrient levels and budgets*

Differences in production levels between conventional and organic Hayward kiwifruit systems in this study, and indeed industry-wide, can largely be attributed to the use of hydrogen cyanamide, a plant growth regulator permitted on conventional, but not organic, orchards that significantly improves bud break and flowering. Nutritional differences may also play a part as Organic fruit are generally smaller than Green and Gold fruit, typically by ~5% (Zespri International, 2008). The Hort 16A (i.e. Gold) kiwifruit variety in particular, is more vigorous than Hayward and, as shown in this study, generally out-yields Hayward. Differences in disease and pest incidence and reject rates (percentage of fruit out-of-grade) may have also contributed to differences in production though these were not measured.

Nutrient inputs for all three orchard systems exceeded outputs, sometimes by an order of magnitude, suggesting inputs may be excessive. Significant amounts of nutrients were added to the organic orchards as composts (with or without manure) and liquid fish preparations but their associated nutrient budgets have a higher degree of uncertainty attached to them due to the more variable composition of the inputs. Under New Zealand law there is no legal requirement to stipulate that a fertiliser maintain a specific nutrient composition (only a voluntary code) and consequently, organic fertilisers require regular independent analysis if their nutrient composition is to be reliably known. For instance, a summary of the main commercial suppliers of major compost products used in kiwifruit orchards showed that the CV% for N, P, K and S content between individual products can be as much as 65% although less for inter-batch variation for a specific product (typically <30% CV). With many of the nutrients bound in organic forms, their release will be over a period of weeks, months or even years and explains the higher mineralisable N values found under organic management. A number of seasons of compost applications are required to attain a cumulative nutrient supply via mineralisation that is similar to annual applications of soluble fertilisers and this, itself, may reduce the impacts of nutrient compositional differences between years. Further, if the nutrient release pattern via mineralisation is in synchrony with the uptake requirements of the crop then nutrient use-efficiency could well be higher than that for conventional systems using one-off applications of soluble fertiliser. These aspects of input composition and availability deserve further study.

Large one-off applications of soluble fertiliser in excess of immediate crop needs can lead to substantial nutrient losses from the system by leaching (Crush et al., 1997) as well as gaseous losses (Harrison and Webb, 2001). These potentially environmentally damaging losses were not measured in this study. However, leaching losses of N from conventional kiwifruit systems have been estimated to be in the range of 40–75 kg N/ha (Mills and Clearwater, 2007) and such losses could potentially be reduced under an organic system. The fact that fertiliser N inputs exceeded removals by 3.5 and 2.4 times, respectively for conventional Green and Gold production systems certainly allows the opportunity for such losses to occur.

The nutrient removed in the greatest amounts in harvested kiwifruit was K and, with the exception of Ca added in lime and organic amendments etc., also comprises for all systems the largest nutrient input. Because of the large removals, K deficiency is the most common macronutrient deficiency encountered in kiwifruit orchards and this can reduce fruit set and subsequent fruit development (Smith, 1996). Although K inputs to organic systems were about half those of conventional ones, the inputs were still double the removals in harvested fruit. Thus, no signs of K stress were apparent in organic systems.

Although P inputs to conventional and organic systems were of the same order, P was applied to conventional orchards mainly in soluble manufactured fertiliser form (e.g. superphosphate), but in organic orchards as sparingly soluble phosphate rock and in composts. Where reactive phosphate rock is applied to soils of high pH (i.e. above 6.5) it characteristically accumulates in soil as residual calcium phosphate which is not extracted with the $NaHCO_3$–Olsen extractant (the standard extractant used for soil testing in New Zealand). It is, however, solubilised, when an anion exchange resin extractant is used (Saggar et al., 1992). The similar linear relationships for each system between Olsen-P and resin-P values for all three systems suggests there was no large scale build-up of residual calcium phosphate in these predominantly acid soils under organic management. The lower Olsen-P and resin-P values under organic systems may well reflect accumulation of inorganic P into non-extractable organic forms induced by the regular applications of organic amendments. Whilst it is known that fertiliser P use-efficiency tends to be low, due to fixation of P by soil colloids in non-available forms (Sample et al., 1980), inputs of P massively exceeded removals in fruit in all three systems. It is unlikely, therefore, that a crop response to P would occur for any system and suggests that P inputs may be excessive.

The greater extractable P values WR than BR may reflect a differential in the way P fertilisers are distributed where more would fall to the soil below the vine canopy (i.e. WR) but this is speculative. Lower soil pH and cation values WR for Green and Gold over Organic probably reflects the use of inorganic N fertilisers under the vines and a general acidifying effect. For conventional Green and Gold orchards, CEC was greater BR than WR (see Section 4.2 below) and as a result the soil held a greater quantity of the dominant exchangeable base, Ca (as well as Mg and K), in exchangeable form.

4.2. Soil organic matter and biology

The greater organic matter content (organic C, total N) under organic than conventional Hayward systems reflects the substantial inputs of organic matter under organic systems (organic manures and composts). Similarly, the higher organic matter content under conventional Gold than Green probably reflects the more vigorous nature of the Gold variety which results in greater organic matter inputs to the orchard floor in the form of leaf drop and prunings. The higher CEC in soils from organically produced Hayward, and to a lesser extent conventional Gold, compared to conventional Hayward, reflects the higher soil organic matter content since humic materials present in organic matter possess a substantial CEC (Stevenson, 1994). A higher CEC will result in the soil having a greater capacity to store potentially plant-available nutrient cations (e.g. Ca, Mg, K) and reduce their leaching losses. The higher pH generally in Organic orchards meant CEC (as measured by ammonium acetate pH 7; Blakemore et al., 1987) was also commensurately greater than for Green and Gold

Interestingly, when soil organic matter content in the surface 15 cm is calculated on a volumetric basis, there are no statistical differences between systems (i.e. Green = 62, Organic = 63, Gold = 64 tonnes C ha^{-1}). This is due to the lower bulk densities under Organic and Gold (see Section 4.3 below). This reflects the fact that as soil organic matter builds up, the topsoil becomes both more porous and deeper.

As has been observed by other workers (Condron et al., 2000), the accumulation of organic matter under the organic system was accompanied by increases in microbial biomass C and N. When microbial biomass was calculated as a percentage of organic C, there were no differences between systems (data not shown) so the increase in the size of the microbial community was proportional to the increased organic matter content. The lack of difference in basal respiration (and metabolic quotient) between systems is probably related to the similar levels of soluble C (and thus available C substrate for soil microflora) present in the soils. It is also possible that as well as differences in microbial biomass, differences in the composition of the microbial community between systems (not measured in this study) may have occurred. In addition, the size of the earthworm community was considerably greater under the organic system. Greater inputs of composts and manures provide more food sources for earthworms thus promoting their growth and reproduction. Springett et al. (1994) previously demonstrated the positive effect of organic management on earthworm numbers in Kiwifruit orchards.

The greater organic C, total N, microbial biomass C and N and mineralisable N content BR compared to WR can be attributed to greater organic inputs BR as this is where prunings are mulched and the area usually has a grass sward cover. In addition, on conventional orchards WR areas receive herbicide and the lack of grass cover would tend to lower organic matter there. That is, whilst grass swards tend to result in a build-up of organic matter, lack of plant cover typically leads to a net loss of soil organic matter (Follett, 2001). Turnover of the large ramified root mass below the grass sod would have resulted in high inputs of organic material and supported a larger microbial biomass and earthworm community BR than WR. Although respiration rate was unaffected by sample position, metabolic quotient was greater WR. An increase in metabolic quotient has been interpreted as a response by soil microflora to adverse environmental conditions (either environmental stress or disturbance (Wardle and Ghani, 1995). The most likely stress within-row compared to BR is likely to a shortage of readily metabolizable-C (although no statistically significant differences were recorded for soluble C WR compared to BR). In the conventional orchards, herbicide applications may have been an additional stress to both the microbial and earthworm communities WR. Nonetheless, the similar trends with sample position under both organic and conventional systems suggest that herbicide applications were not a major contributor to the stress effect.

4.3. Soil physical condition

Soils from organic systems possessed the lowest bulk density, highest water content at field capacity, and highest proportion of good and excellent scores for porosity and to a lesser extent, aggregation. Vogeler et al. (2006), working on apple orchards, also found that soil physical conditions were generally improved under organic compared with integrated management. The inputs of compost and organic manures to the organic systems (and consequently the higher organic matter content) is likely to be the main contributor to this effect. Indeed, a decrease in soil bulk density and increase in water holding capacity in response to applications of organic manures and composts has been observed in a wide range of soils and cropping systems (Khaleel et al., 1981; Riley et al., 2008) and is beneficial in these free-draining soils. The greater earthworm numbers under organic management would also contribute to the lower bulk density and greater porosity since their burrowing activity is known to produce stabilized macropores. In addition, anecdotal observations at the orchard sites suggest that there may be less overall machinery traffic (to mow, apply sprays and fertilisers) in organic kiwifruit orchards and this will tend to reduce compaction, particularly BR.

Although there were no differences in bulk density or water holding capacity between WR and BR soils in any of the systems, VSA assessments showed pronounced differences. The greater aggregation BR compared to WR is attributable to the aggregating effect of grass sward roots whilst the less porous nature of BR soil is due to wheeled and foot traffic in the inter-row lanes.

4.4. Economic and system sustainability

Despite the lower production levels for the organic orchards in this study (which mirrors industry trends), the average operating surplus has been higher than for Green. The premiums currently achieved in the market for Organic fruit strongly drive this difference. Gold's significant higher production levels and high tray prices make this a financially attractive variety although it is more difficult to grow well. Also, the amount of Gold fruit that can be grown is regulated.

Whilst supplies of fertiliser are readily available to Conventional systems, these have in recent times increased in cost, especially where their supply is strongly linked to the use of fossil fuels. Nevertheless, inorganic fertilisers often still appear economical on a per unit nutrient cost compared with their Organic counterparts and their transport and application are often easier. The large amounts of nutrients being added to the organic orchards as composts and liquid fish preparations have to be bought in from commercial suppliers. Most commercial compost is derived from clean green waste material and may be mixed with chicken or other manures to increase available P and N content. These sources have to be approved by an Organic certifying organisation (BioGro NZ, 2001) but may not necessarily themselves be derived from the green residues or excreta of other Organic systems. Consequently, it is difficult to know if the Organics industry continues to expand, whether it can be self-sufficient in these source materials without resorting to organic wastes and residues from more Conventional systems and whether the cost of these inputs will, consequently, escalate with demand.

5. Conclusions

Simple input/output nutrient budgets at the orchards in this study showed that nutrient inputs greatly exceeded removals in the harvested crop for all measured nutrients (i.e. N, P, S, K and Mg) in all three systems. Even taking into account potential fixation/immobilization by soil components, nutrient inputs seem excessive and there is potential to reduce them, especially in conventional systems where inorganic inputs are the norm. The sources used in Organic systems, however, are more slowly soluble and/or dependent on OM mineralisation and may require more careful monitoring at critical times if inputs are cut back. Quantification of nutrient losses (e.g. leaching and gaseous) from the current systems is a future priority. Despite the differences in nutrient sources used, there were generally few major differences in available nutrient levels between organic and conventional systems demonstrating that long-term soil fertility can be adequately maintained under organic management. Indeed, some benefits to soil properties accrued from additions of OM under organic management including a lower bulk density, higher water holding capacity and larger earthworm communities. Organic orchards, however, are still a relatively small proportion of orchards overall (~5%) and the ability to provide sufficient Organic-approved nutrient inputs to shift all orchards towards more sustainable practices could be difficult. Although Organic generally produce less fruit, mainly because of nutritional and varietal differences and the absence of synthetic plant growth regulators, comparatively good returns and surpluses can still be achieved.

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