THE IMPACT OF KIWIFRUIT MANAGEMENT ON ALLOPHANIC SOIL QUALITY: PHYSICAL, CHEMICAL AND HYDROLOGICAL PROPERTIES

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Abstract
Management of kiwifruit-producing soils in New Zealand varies widely with special techniques depending on agro-ecological zones. The diverse kiwifruit management systems can have significant impacts on soil quality indices. We hypothesised that physico-chemical indicators of soil quality would be higher in soils under shaded kiwifruit management systems compared to the grassland management system. In order to assess the impact of land use on soil quality properties in a kiwifruit ecosystem of New Zealand, soil samples were collected at 0-100cm depth from a kiwifruit orchard of vines aged seven years old and thirty years old. Soil samples were collected from grassland adjacent to the kiwifruit as paired samples. The study site was on allophanic orthic pumice soil (Vitrads/Vitriccryands Andisol, USDA; Mollic Andisol FAO) formed from volcanic parent material. Land management resulted in bulk density being highest in grassland followed by 7-year-old kiwifruit vines and the lowest in 30-year old kiwifruit vines. In grassland soils, higher values for sand content and lower values for silt and clay content were recorded in comparison to kiwifruit soils. Higher sand content combined with poorer aggregation could account for the higher bulk density under grassland in comparison with the kiwifruit soils. The decrease in silt+clay content in grassland soils is likely a result of the removal of fine particles by accelerated water erosion. Total organic C, N, electrical conductivity (EC), maximum water holding capacity, field water holding capacity and hygroscopic moisture all increased under kiwifruit vine managed soils. The 30-year-old vine soils have higher nitrogen and carbon contents in comparison to the other soils, as it is permitted to grow nitrogen fixing cover crops. Lower pH values were observed in the grassland management system than that of 30-year-old kiwifruit soils. In grassland soils, the intense leaching of basic cations during irrigation and/or precipitation is the likely contributing factor to lower pH levels. Additionally, the input of lime has contributed to the higher pH in kiwifruit soils. The overall improvement of soil properties under the kiwifruit management systems indicate that expansion of well-adapted and rapid-growing agro-forest species can gradually improve soil quality and ameliorate degraded soils.

Introduction

The management practice of a soil has the ability to alter the soils physical, chemical and hydrological properties (Rahman et al., 2008). Ideal soils should be porous and have other desirable qualities that enable it to be less compact, hold more water, and have more available elements and nutrients. Ideal soils also have the potential to act as a carbon sink, conserving carbon in the soil and lowering the amount lost to the atmosphere. Kiwifruit orchards are small scale, highly intensive systems (Carey et al., 2009), which are vital for New Zealand's export industry. They are wide spread across New Zealand, but more that 60% of New Zealands kiwifruit orchards are located in the Bay of Plenty region on allophanic soils, with their growth both influencing the soil quality as well as being influenced by soil qualities (Rahman et al., 2011a). In response to increasing world population and climate change, it is essential to modify intensive horticultural systems to keep them financially viable and environmentally responsible as well as efficient producers of highly nutritious food products. Scarcer water resources, rising atmospheric concentrations of greenhouse gases (GHG), and markets that demand a low carbon footprint of produce are typical environmental and economic consequences of climate change. Management of kiwifruit-producing soils in New Zealand varies widely with special techniques depending on agro-ecological zones. The diverse kiwifruit management systems can have significant impacts on soil quality indices. Study of soil management practices for kiwifruit orchards will provide New Zealand growers with the tools to adjust their production systems to mitigate and adapt to these consequences; and by doing so enable them to exploit the emerging business opportunity in marketing 'green' produce. The aim of this research is to discern whether kiwifruit vine management over time results in a positive impact on soil quality over other land management systems.

Materials and Methods

In this study, the Roddaal Orchard containing kiwifruit blocks aged seven years old and thirty years old was selected. Soils from grassland adjacent to the kiwifruit were also sampled as paired samples. All the study sites were located in the Bay of Plenty region, Te Puna, in the North Island of New Zealand. Both kiwifruit blocks are conventionally managed and grow green Hayward kiwifruit (*Actinidia deliciosa)*. The soil at the experimental site is classified as Allophanic Orthic Pumice soil (Vitrads/Vitricryands Andisol, USDA; Mollic Andosol, FAO) formed from volcanic parent material. The soil was sampled from three different soil horizons to a maximum depth of 100 cm. Samples were taken from 0-28, 28-60, 60-100cm depths, the horizons were established from observation of the orchard soil depending on soil colour and structure. Nine undisturbed samples were collected from each site using Daiki soil sampler using 100-cc cores. Disturbed soil samples were also collected from the same place. Each soil sample was placed in a plastic bag and kept at room temperature (21°C) until it was processed in the laboratory. Fifty grams of disturbed soil was removed immediately for colour determination, pH, EC and N testing. The rest of the disturbed soil samples from each site were sieved (<2mm sieve) to remove visible plant litter, rocks and roots in the laboratory. After sieving, soil samples were placed in aluminium cups and air dried for at least 24 hours before testing for physical, chemical and hydrological properties. Bulk density at each soil depth was determined using the core method (Blake and Hartge, 1986) from undisturbed core samples. Porosity for each undisturbed sample was calculated according to Kezdi (1974). Sand, silt and clay was determined using the sedimentation method laid out by Gee and Bauder (1986) after air drying disturbed soil samples for 48 h, and the textural class of the sites soil was determined using the USDA classification scheme. Soil pH was determined using an IQ Stainless Steel ISFET pH probe in a 1:2.5 soil-to-water suspension (Jackson, 1973). Electrical conductivity (EC) was measured by an IQ Conductivity Probe (Kalra and Maynard, 1994). Soil organic carbon (SOC) was measured using the loss-on-ignition method developed by Rahman et al. (2011b). Maximum water holding capacity, field capacity, gravitational drainage and hydroscopic moisture was measured using the methods set out by Gardner (1986).

Results and Discussion

All physical properties in this experiment were affected to some degree by management practice (Table 1). The properties studied were strongly influenced by how long the kiwifruit vines had been growing on them and thus the management practice of the soil. Bulk density of the soil significantly decreases with management land practice, decreasing as the kiwifruit vines become older. This could be due to the result of weathering or the development of a more porous structure due to the increase of organic matter (Prado et al., 2007). There is also a significant increase in the soils porosity that also correlates to the age of the kiwifruit vines, as shown in the Table 1. An increase in porosity increases the ability for water to infiltrate and be stored in the soil (Kay and Vanden Bygaart, 2002). The results indicate that not only is the soil less compact, the site where kiwifruit have been established longer can hold more water. There was no discernable change to the soils textural class.

Table 1. Soil physical properties of study sites.

Management	Depth (cm)	Bulk Density (Mgm^{-3})	Porosity (%)	Sand (%)	Silt (%)	Clay (%)	Textural Class* (USDA)
	0-28	0.86	66.58	39.15	16.05	44.80	C
Grass	28-60	0.93	63.86	48.74	9.67	42.59	SC
	60-100	0.94	63.23	43.20	11.03	45.76	C
	0-28	0.83	67.46	33.60	18.18	48.22	C
7 years	28-60	0.84	67.20	48.04	8.23	43.72	SC
	60-100	0.92	64.04	41.75	10.51	47.74	C
	0-28	0.76	70.27	35.19	15.82	48.99	C
30 years	28-60	0.82	67.82	45.40	7.69	46.92	SC
	60-100	0.90	64.90	43.88	8.48	47.64	C

*C = Clay; SC = Sandy Clay

While bulk density and porosity show good correlations, there is a less consistent trend associated with the results from the particle size analysis. While the other results suggest that there would be some kind of association between all physical properties and management practices, we do not observe as obvious a trend as with bulk density and porosity. We have taken enough precautions to measure particle size distribution as the measurement of particle size distribution in allophane-dominated soils is difficult due to allophane flocculation (Soil Survey Staff (1956), which prevents complete particle dispersion. Other scientists (Kobo, 1964; Colmet-Daage et al., 1972) agreed with this idea, which can help explain why the sand, silt and clay fractions do not show a confident trend, unlike the other physical properties. It is therefore, necessary to measure particle size distribution with different methods to find consistent results.

While there is no evident change in soil pH over management practice, there is significant variation with soil electrical conductivity and soil organic carbon, both increasing as vine age increases (Table 2).

Table 2. Soil chemical properties of study sites.*

Management	Depth (cm)	pH	EC (µS/cm)	Ionic strength (mole/l)	SOC (%)	NO_3-N (ppm)	NH_4-N (ppm)	Total N (%)
Grass	0-28	6.2	223.2	0.29	3.48	74.8	111.3	0.32
	28-60	6.8	182.3	0.24	0.48	65.8	102.4	0.08
	60-100	6.7	152.7	0.20	0.16	61.7	98.5	0.04
7 years vine	0-28	6.0	341.0	0.44	3.82	73.8	110.1	0.36
	28-60	6.2	349.8	0.45	1.32	71.9	108.3	0.14
	60-100	6.6	162.7	0.21	0.21	66.3	103.1	0.05
30 years vine	0-28	6.2	411.2	0.53	4.42	94.4	131.8	0.41
	28-60	6.5	467.9	0.61	1.40	66.0	104.3	0.15

It seems from these results, that the kiwifruit vines seem to cause the soil pH to drop to a relatively stable level that persists over a long time period with little change between the blocks growing kiwifruit. Electrical conductivity indicates the amount of soluble salts (cations or anions) in the soil (Friedman, 2005). An increase in EC shows an increase in the concentration of these dissolved inorganic solutes, which are available to plants in this form. There are the highest EC values in the thirty year management block, which suggests that there is the largest amount of inorganic substances available to the kiwifruit vines in this block. The greatest percentage of soil organic carbon in the three management blocks was found in the thirty year block. An increase in soil organic carbon can also indicate an increase in microbial biomass, with a positive relationship seen between organic carbon and bacteria and fungus (Frey et al., 1999). As agricultural crops hold significantly less soil carbon than native forests (Bayer et al., 2002; Stevenson 1994), we can infer that the thirty year block is closest to the original natural state of the land, and is of better quality than the other two management sites.

The hydrological results all indicate that the soil of the experimental site retains more water depending on the specific management practice. There is an overall increase in both maximum water holding capacity and field capacity as the kiwifruit age (Table 3).

The data also shows that there is a decrease in gravitational drainage in response to the age of the kiwifruit vines. The increase in field capacity shows that the thirty year block is able to hold more moisture. In complement, the drop in gravitational drainage reinforces that the soil is holding more moisture in the older block, meaning less water is escaping into groundwater (Soil Science Society of America, 1986). Hydroscopic moisture also follows a similar trend as the other hydrological parameters, indicating that due to management practice, more water is being retained in the soil through capillary action in the microscopic spaces in the soil. There is a strong relation between available water and crop production potential (Fraisse et al., 2001). Our results show that the 30 year old block should therefore be the most productive.

Table 3. Soil hydrological properties of study sites.*

Management	Depth (cm)	MWHC (%)	FC (%)	GD (%)	HM (%)
	0-28	77.58	66.09	11.49	6.16
Grass	28-60	68.36	58.87	9.49	5.39
	60-100	67.61	60.35	7.26	4.50
	0-28	74.81	67.90	6.92	7.48
7 years	28-60	73.53	67.71	5.82	6.80
	60-100	66.33	61.28	5.05	5.22
	0-28	87.48	81.19	6.29	8.82
30 years	28-60	83.71	78.07	5.65	6.84
	60-100	69.81	66.75	3.06	5.48

* MWHC = Maximum Water Holding Capacity; FC = Field Capacity; GD = Gravitational Drainage; HM = Hydroscopic Moisture

The results indicate that there is an overall increase in soil quality associated with vine management practice. However, the influence the kiwifruit have on the soil in this experiment is limited to the depths of their roots, typically reaching only 100cm in depth. This is shown in the results as there is the least amount of variation between the three management practices at the 60-100 cm sampling depth. This also shows the importance the kiwifruit roots play on influencing the soils physical, chemical and hydrological properties. Overall, it appears that the longer the soil is influenced by kiwifruit, the more positive qualities it attains such as decreasing bulk density, becoming more porous, retaining more water and holding more carbon. Theses have many positive benefits associated with them. The soils are less compacted with more space to hold water which means less surface water and runoff, as well as the positive benefits of the soil becoming a carbon sink, retaining more carbon as the vines age. This is not only important for the health and growth of the kiwifruit, but it also plays and important part in the attempt to lower greenhouse gas emissions, sequestering carbon in the soil which would otherwise be lost to the atmosphere as carbon dioxide (Smith, 2004).

Conclusion

The overall improvement of soil properties under the kiwifruit management systems indicate that expansion of well-adapted and rapid-growing agro-forest species can gradually improve soil quality and ameliorate degraded soils.

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