A Benefit/Cost Assessment in Citrus IPM Following the Application of Soil Amendments

Dr Peter Crisp
South Australian Research and Development Institute (SARDI)

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Statement about the purpose of the report
This report details the research and extension delivery undertaken in Project CT10022 on the suppression of *Bactrocera tryoni* oviposition by bacteria isolated from the gut of *Dirioxa pornia*. Main findings, industry outcomes and recommendations to industry along with suggested areas of future research are discussed.

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1. Media Summary

Kelly's citrus thrips (KCT) is a key pest of citrus in the Riverland-Sunraysia region. KCT feeding on developing fruit causes scurfing and rind bleaching, thereby reducing the packout of export quality fruit and rendering some fruit unsaleable.

As reported in CT06007 (Crisp *et al*. 2009) KCT control programs rely heavily on application of organophosphate insecticides, however, KCT are developing resistance to these measures resulting in increased spraying and IPM disruption. CT06007 demonstrated that applications of composted soil amendments increase soil carbon, which enhances populations of soil-dwelling predatory mites and reduces the emergence of KCT from the soil by more than 50%. Building on data gathered in earlier projects, this new study aimed to further investigate the longevity of the beneficial effects of applying soil amendments, which include increased predatory mite densities, reduction in KCT damage and improved yields. The compost treatments which were applied in 2006 included recycled green organics, grape mark and animal manure.

The key outcomes were:

- Application of soil amendments maintains higher soil moisture levels in the top 25 cm of soil than untreated controls for at least 6 years and would appear to last significantly longer than that.
- Soils to which composts have been added have significantly higher nitrogen and other nutrient levels.
- Significant increases in yield recorded in CT06007 in plots where soil amendments were applied (up to 60% increase over untreated controls) persisted up to four years after application, particularly where composted green waste was used, displaying a direct relationship between application rate and yield.
- Fruit from trees treated with soil amendments were larger diameter, and in most cases fruit density was also higher.
- Benefits achieved from application of the composted green waste appear to be more robust and longer term than those from the other soil amendments used.

2. Technical Summary

Kelly's citrus thrips (KCT), *Pezothrips kellyanus* (Bagnall), is a key pest of Navel and Valencia oranges, lemons and grapefruit in the Riverland-Sunraysia region and to a lesser extent in Western Australia and the Riverina. KCT feeding on developing fruit causes scurfing and rind bleaching, reducing fruit quality, thereby reducing fruit packout of export quality fruit and rendering some fruit unsaleable.

Currently control programs rely heavily on application of organophosphate insecticides, however, KCT are developing resistance to these measures resulting in increased spraying and IPM disruption. Soil-dwelling predatory mites have been identified as a potential biological control and where their populations are high the emergence of KCT from the soil is reduced by more than50%. Building on data gathered in projects CT97007 (Baker et al 2000) and CT00015 (Baker et al 2003), this new project aimed to investigate the potential for boosting predatory mite densities using several compost treatments to provide effective reduction in KCT damage. The compost treatments included recycled green organics, grape mark and animal manure. Additionally the project aimed to assess the effect of run-off that results from the application of synthetic insecticides applied largely to control KCT. The economic and environmental sustainability of IPM of KCT using soil amendments and decreased application of insecticides was assessed.

The Project Science

- Studies to determine the ongoing effect of soil amendments on soil carbon levels and populations of predatory mites in citrus soils
- Fruit yields were assessed as was the size and quality of harvested fruit to enable financial data to be collected for economic analysis.

The Key Research Findings, Extension Highlights and Industry Outcomes

- The increases in populations of fungivorous and detritivorous arthropods and predatory mites and increases in soil carbon levels after the application of composted green waste under citrus trees continue to persist beyond 6 years. The increase in the beneficial soil-arthropod population was greatest in soil that had received the composted grape mark treatment, however at lower rates of compost and all animal manure treatments the effect had become negligible after 5 years.

- The effect of higher soil moisture levels in the top 25 cm of amendment-treated soils compared to the untreated controls persisted up to at least 6 years and is expected to persist well beyond that.
    - The application of composted green waste and grape mark significantly increased soil moisture levels in the top 25 cm of the soil profile, providing the potential to reduce irrigation levels without having a negative effect on yield and tree health.
- Soils to which composts have been added have significantly higher levels of plant available nutrients including nitrogen.
    - Soil nitrogen levels in soil where soil amendments were added were significantly higher than control soils. Whether this is a result of initial application with the soil amendments, reduced leaching or increased fixing through increased microbial activity was not determined.
- Yield gains seen in the first three years of the research continued in the fourth year at both the Loxton North and Loxton Research Centre sites, particularly where the higher rates of amendments were used. However, other management practices made further economic analysis unreliable.
- Benefits achieved from application of the composted green waste soil amendments in 2006 appear to be more robust and long term than from other composts used, particularly in the case of animal manure which had little effect beyond three years.

3. Introduction

Since the early 1990's damage from Kelly's citrus thrips (KCT) feeding in the Riverland-Sunraysia has reduced the packout of export-quality oranges, grapefruit and lemons, and rendered some fruit unsaleable. In turn, the control of KCT has been restricted to the use of foliar organophosphate (OP) insecticides, which disrupt the biological control of other important citrus pests, and of KCT itself.

While KCT populations and resultant damage vary between seasons in unfavourable years, despite the application of 1-5 thrips sprays, an average of 20-40% of the fruit of these varieties can be rendered unsaleable for quality fresh markets. A 2003 survey revealed that Riverland navel orange producers alone lose on average around $9+ million per annum from KCT.

Project CT00015 identified complexes of predatory arthropod populations, predominantly mite species, that kill the soil-dwelling pupae of KCT in Australian citrus orchard soils, and at times substantially contribute to KCT population regulation. Orchards with abundant populations of soil predators have high levels of KCT pupal mortality and low incidence of KCT damage. Further, the abundance of these soil predators was shown to be positively correlated with the amount of soil organic carbon in the orchards.

The synthesis of a conservation biological control system in CT06007 showed significant financial and environmental benefits associated with the application of composted soil amendments to citrus orchard soils. The amendments improved the biological control of KCT and demonstrated ongoing persistence and provided positive financial returns throughout the 3 year duration of the CT06007 trials. This was particularly so for the composted recycled green waste treatments. There was also an apparent sequestration of carbon in the soil, as soil carbon increased during the life of the trial, which could provide long term economic and environmental benefits. However, the longevity of these benefits is unknown as is the long term effect of the treatments on populations of beneficial arthropods in the soil. Benefit cost analysis conducted as part that CT06007 was based on conservative estimates of the longevity of the soil amendments, which in reality may be considerably longer than the three years of CT06007 has allowed us to quantify. Nevertheless, benefit cost ratios of up to 5:1 were estimated in the CT06007 economic analysis. Additionally, the analysis of soil water samples taken during CT06007 has revealed some changes to soil chemical properties which require further investigation.

A key to the success of this project and the IPM system under development is a partnership with commercial suppliers of soil amendments.

In summary this research project was proposed to provide the citrus industry with management details required to make sound knowledge-based decisions that ensure a sustainable and successful IPM system for KCT. Finally, the potential of the composting component of this IPM system to substantially improve fruit size and water-use efficiency over a seven year period, with their potential market and cost-reduction advantages, was to be fully investigated.

4. Materials and Methods

Soil Amendment Studies

The research sites were those established for CT06007 in October 2006 (Valencia orange block at Loxton RC, Navel block at Loxton North). At Loxton Research Centre five rates of composted garden-waste (40, 80, 120, 160 and 200 m^3ha^{-1}), two rates of grape-mark(100 and 200 m^3ha^{-1}), four rates of screened composted animal manure (10, 20, 30 and 40 m^3ha^{-1}) plus an untreated control were applied to four tree plots in a four-replicate randomized block design. At Loxton North three rates of composted green waste (40, 120 and 200 m^3ha^{-1}), screened composted animal manure (40 m^3ha^{-1}) and aged grape mark (200 m^3ha^{-1}) were compared with the untreated control. The soil amendments were applied in at each site in 2006 and no further applications were applied as part of this research.

The soil biota: Populations of mites and Collembola were estimated by taking 500 ml scrapes from the top 5 cm of soil under the drip line of citrus trees. Samples were placed in sealed plastic bags and transported in a cool esky and kept dark, and within 48 hours of collecting 3 x 150 ml sub-samples were placed on Berlese funnels and arthropods collected in 80% ethanol and stored for counting and identification. Mites selected for identification were slide mounted in Heinz PVA (Evans, 1992).

Soil pH and EC were assessed after each irrigation cycle using water samples collected using Solu-samplers, however, due to the withdrawal of funding support this analysis could not be completed.

Fruit yield per tree, mean fruit size, rind thickness and Brix (soluble solids) levels were assessed in 2011 and 2012 by sampling in the first two years but were not able to be completed for the 2013 season.

Soil carbon

250 g soil scrapes were taken from the 0-50 mm and 50-100 mm profiles of the soil in 2011 and 2012 and the organic C content calculated by Veolia Environmental Services using aerobic combustion. Soil samples collected in 2011 for carbon analysis were also analysed for total and soluble nutrient profiles by Veolia laboratories.

Economic Analysis

The economic analysis model and the costs and benefits of compost application from CT06007 was to be streamlined and estimated for years 4 -7 with actual data, including fruit prices received, application rates, costs of applying, reapplication frequencies, yields and quality. Other factors such as water conservation, weed control, soil quality and sustainability issues were to be included in the analysis to assist producers to make day to day management decisions for the control of KCT and other orchard management. Yield data for 2012 was confounded by the application of 5 m^2 of composted piggery waste per hectare in 2011 and 2012. In 2012 there was a marked reduction in differences in yield from trees receiving all treatments in 2006 While this may be the result of the additional compost it is also possible that the reduction in yield differences among treated trees can be attributed to exhaustion of the beneficial effects of the application of the soil amendments. However, 2012 yields are significantly higher than in previous seasons suggesting the addition of extra composted animal material may have been the cause.

Results of the Loxton Research Centre harvest were confound when the orchard was hedged through the 2011 season and yield has been severely affected by the treatment. In addition, funds were not available to pay for additional costs of collecting data at harvest in 2012. The pruning was conducted by the orchard manager and was necessitated by the tree branches restricting access to the rows for harvesting and maintenance machinery. This is normal practice from time to time in orchards and as the trial site had been established for several years it was likely to happen eventually. When trying to construct the final benefit cost analysis, the unknown cost of the treatments at Loxton North, the hedging of the trees and unavailability of the final year's data the decision was made that any figures presented would be unreliable and would not stand up to thorough scrutiny and as a result the BCA was not completed.

5. Results

Yield data

At Loxton North the previously observed trend of significantly higher yields from trees treated with composted soil amendments continued in until 2011 (Table 1). From 2011 the relative yield difference between treatments decreased, this may have been due to the grower applying approximately 5 m^2 of composted piggery waste per hectare in 2011 and 2012. It is also possible that the reduction in yield differences among treated trees can be attributed to exhaustion of the beneficial effects of the application of the soil amendments, however, 2012 yields are significantly higher than in previous seasons suggesting that he additional soil amendments affected yield and confounded the results. Late 2010 and 2011 also saw an increase in rainfall compared to the previous 4 years (Table 3) that carried into 2012 and may have also negated the benefit of increased soil moisture retention in soils treated with composted soil amendments. This increased rainfall may have contributed to the general increase in yield for all treatments in 2012.

Table 1: Average yield of Navel Oranges at Loxton North (2007-2012).

Average yield of oranges per m^2 of tree canopy (kg) for navel trees at Loxton North treated with a single application of composted soil amendments in 2006. Yield as a % of control in brackets. $^+$ Yield is significantly higher than controls, *Approximately 5 m^3 ha^{-1} composted piggery waste was added in 2011 and 2012.

Treatment (m3 ha-1)	2007	2008	2009	2010	2011	2012
Control	4.6 (100)	4.4 (100)	6.8 (100)	5.7 (100)	5.7 (100)	10.8 (100)
Animal 10	4.8 (104.3)	5.6$^+$ (127.3)	7.7$^+$ (113.2)	6.8$^+$ (119.3)	6.7 (117.5)	9.9 (91.7)
Compost 40	5.1 (110.9)	5.1 (115.9)	7.8$^+$ (114.7)	7.2$^+$ (126.3)	6.1 (107.0)	11.5 (106.5)
Compost 120	5.4$^+$ (117.4)	6.3$^+$ (143.2)	8.5$^+$ (125)	7.4 $^+$ (129.8)	5.9 (103.5)	10.4 (96.3)
Compost 200	5.8$^+$ (126.9)	6.6$^+$ (150.0)	8.1$^+$ (119.1)	7.3$^+$ (128.7)	6.4 (112.3)	10.8 (100)
Grape mark 200	5.8$^+$ (126.9)	7.1$^+$ (139.5)	8.2$^+$ (118.5)	6.5 (123.5)	6 (109.1)	10.4 (96.3)
F. Pr	0.0086	>0.0001	0.0427	0.0026	0.546	0.754

The Valencia trial at Loxton Research Centre showed a similar trend to the Navel trial at Loxton North where higher yields from trees treated with composted soil amendments continued until 2011 when yields from trees with treated soil were not significantly different from control trees (Table 2). Severe pruning in 2010 resulted in minimal and zero yields for many trees, however, the yield from trees treated with the various soil amendments was significantly higher than the controls and in 2011 yield differences appeared to return to similar levels as seen prior to the pruning. In late 2010 and 2011 there was a general increase in rainfall (Table 4) in the region which, along with a reaction to the previous year’s low yield due to pruning, may have contributed to the significant increase in yield for all treatments in 2011. Although the rainfall increased in 2010, it was late in the year and post-harvest, therefore not affecting yields for 2010 but providing ideal conditions for fruit development in 2011. In 2012 yields were low, most likely as a response to the high yields in 2011 and, while not significant, the trend of higher yields from trees treated with composted green waste and composted grape mark continued.

Table 2: Average yield of Valencia oranges at Loxton Research Centre (2007-2012).

Average yield of oranges per tree canopy (kg) for Valencia trees at Loxton Research Centre treated with a single application of composted soil amendments in 2006. Differences in yield (%) for Valencia trees at Loxton Research Centre compared with untreated control trees (100%). $^{+}$ Treatments with yields significantly higher than controls. $^{-}$ Treatments with yields significantly lower the controls.

Treatment	2006	2007	2008	2009	2010	2011	2012
Control	66.4	32.7	73.3	97.1	3.4	180.3	23.5
	(100)	(100)	(100)	(100)	(100)	(100)	(100)
Compost	77.0	39.2	110.2^{+}	103.3	5.2	196.2	24.8
(40 kg/ha)	(116)	(119.9)	(150.3)	(106.4)$^{+}$	(153.8)	(108.8)	(105.5)
Compost	74.8	39.4	132.6^{+}	96.6	10.2^{+}	206.3	37.1
(80 kg/ha)	(112.7)	(120.5)	(180.8)	(99.5)	(302.8)	(114.4)	(157.9)
Compost	77.5	37.0	150.9^{+}	79.9	10.6^{+}	229.4	29.6
(120 kg/ha)	(116.7)	(113.4)	(205.8)	(82.3)	(313.3)	(127.2)	(126.0)
Compost	69.7	41.4	146.2^{+}	80.2	10.7^{+}	195	37.4
(160 kg/ha)	(105.0)	(126.6)	(199.4)	(82.5)	(317.6)	(108.2)	(159.1)
Compost	69.8	38.1	168.3^{+}	94.7	11.9^{+}	225.6	28.5
(200 kg/ha)	(105.1)	(116.5)	(229.5)	(97.5)	(353.4)	(125.1)	(121.3)
Animal	60.0	39.5	148.6^{+}	52.9^{-}	13.4^{+}	200.9	29.9
(10 kg/ha)	(90.4)	(121.0)	(202.6)	(54.4)	(396.9)	(111.4)	(127.2)
Animal	56.6	40.3	169.3^{+}	86.5	16.5^{+}	217.7	16.2
(20 kg/ha)	(85.2)	(123.2)	(230.8)	(89.1)	(487.2)	(120.7)	(68.9)
Animal	56.3	30	106.5^{+}	69.2	16.7^{+}	194.7	18.3
(30 kg/ha)	(84.8)	(91.7)	(145.2)	(71.2)	(493.2)	(108.0)	(77.9)
Animal	43.2	20.6	110.0^{+}	31.0^{-}	20.1^{+}	173.4	20.8
(40 kg/ha)	(65.1)	(63.1)	(150.0)	(31.9)	(595.2)	(96.2)	(88.5)
Grape	65.1	29.3	146.4^{+}	89.7	22.2^{+}	190.6	26.9
(100 kg/ha)	(98.0)	(89.9)	(199.6)	(92.4)	(657.7)	(105.7)	(114.5)
Grape	75.5	28.3	171.3^{+}	87.9	26.2^{+}	148.9	81.6
(200 kg/ha)	(113)	(86.8)	(233.5)	(90.5)	(776.9)	(82.6)	(115.3)
F.Pr (5%)	0.671	0.470	<0.001	0.045	<0.001	0.366	0.348

Table 3: Rainfall (mm) for Loxton Research Centre 2006-2012

Month	2006	2007	2008	2009	2010	2011	2012	Average
Jan	6.4	59.6	11.6	0.2	8	99.2	28.8	18.3
Feb	7.6	3.8	1.2	0	25	48.1	2.1	19.9
Mar	36.4	28.8	0.4	1.5	34.4	23	51.6	12.8
Apr	41.4	34.6	9	24.4	17.4	6.2	9	17.2
May	9.4	50.1	34	4.6	47.1	18	7.2	23.2
Jun	8.4	2.5	20.2	21	11.8	9.4	9.2	25.9
Jul	29.4	27	26.8	25.4	28.1	24	27.8	27.7
Aug	5.2	2.6	27.2	15.6	31	38.2	14.9	26.5
Sept	7.4	6.8	5.8	38.8	61.8	6.8	5.9	26.7
Oct	0.2	12.2	4.6	13	50.6	32.2	8.8	26.0
Nov	10.6	35.4	26.9	47.7	33.2	43.6	4.4	21.2
Dec	8.8	14.1	31.6	22.2	125.6	52.2	10.6	25.4
Total	171.2	277.5	199.3	214.4	474	400.9	180.3	270.8

Arthropod population densities at Loxton Research Centre were generally less in soil samples taken from control plots in 2011 than from plots with soil amendments added in 2006, particularly where the amendments had been applied at higher rates (Table 4). Predatory mite populations were highest where soil amendments were added to the soil, particularly at the higher application rates. Populations of predators in soil samples collected from controls, and where the lowest compost rate and lowest two rates of animal manure had been added, were of similar density to those collected prior to the treatment application in 2006 (4.0 predators per sample).

Table 4: Number of selected soil arthropods in 125 ml soil in February 2012 from Loxton Research Centre.

Samples extracted from the top 2.5 cm of soil from under citrus trees at Loxton Research Centre, treated with soil amendments in October 2006. Extractions were conducted using Tullgren funnels. Data with different letters are significantly different (5%).

Loxton Research Centre

Treatment (m^3 ha^{-1})	Collembola	Oribatid mites	Other mites	Predatory Mites
Control	44 bc	0.1 b	1.35 b	2.2 c
Compost 40	44 bc	0.58 ab	1.14 b	3.95 c
Compost 80	55.5 abc	0.72 a	0.5 b	11.5 ab
Compost 120	74.6 a	0.77 a	0.57 b	7.9 bc
Compost 160	67.5 a	0.83 a	0.86 b	7 bc
Compost 200	62.5 ab	0.65 a	0.57 b	9.14 b
Mark 100	37.8 b	1.29 a	1.7 b	11.9 ab
Mark 200	79.5 a	0.82 a	5.46 a	13.6 ab
Animal 10	33.4 c	0.01 b	0.88 b	4.5 c
Animal 20	36.2 c	0.25 b	0.52 b	5.1 c
Animal 30	44.1 bc	0.01 b	0.72 b	9.4 b
Animal 40	76.6 a	0.18 b	1.1 b	18.5 a
Significance	<0.001	0.006	<0.001	0.001

The population densities of predatory mites in the soil at the Loxton North site, in 2012, reflect the application of soil amendments across the entire area for the past two years with populations in the untreated control plots as great as any of the treatments except the grape mark treatment (Table 5) and all plots with significantly greater populations than prior to application of the soil amendments in 2006 (0.28 predators per sample).

Table 5: Number of selected soil arthropods in 125 ml soil in February 2012 from Loxton North.

Soil samples extracted in from the top 2.5 cm of soil from under citrus trees at Loxton North, treated with soil amendments in October 2006. Extractions were conducted using Tullgren funnels. Data with different letters are significantly different (5%).

Treatment (m^3 $ha^{-1)}$	Collembola	Oribatid mites	Other mites	Predatory Mites
Control	16.8	0.5	3.41 ab	6.23 b
Compost 40	10.2	0.8	1.15 c	3.9 c
Compost 120	19.8	0.7	1.61 bc	5.13 bc
Compost 200	21	0.8	3.11 ab	5.96 b
Mark 200	20.6	0.9	4.29 ab	10.0 a
Animal 40	18.2	0.3	2.22 bc	4.09 c
Significance	**NS**	**NS**	**0.029**	**0.002**

Soil Carbon and Nitrogen

Soil carbon (% and total) and total nitrogen levels in soils treated with the various soil amendments was significantly higher than in control soils at both depths sampled in 2012 (0-5cm and 5-15 cm) (Table 6). It is unclear if the higher organic carbon at depths below 5 cm was the result of carbon moving through the soil as a result of water and biological action or increased root mass associated with improved soil, and nutrient profiles which resulted from the addition of the soil amendments. Total nitrogen in the top 5cm of soil or samples collected in 2011 was higher in soils treated with soil amendments in 2006 than in control soils (Table 6).

Table 6: Soil carbon in soil samples collected at 2 depths from Loxton North in May 2012.

Soil amendment treatments were applied in 2006. Total nitrogen was calculated from the samples taken at 0-5 cm depth.

Treatment	Soil Carbon % (W/W)		Soil Carbon Tonnes/ha		Total Kjeldahl Nitrogen %
	0-5 cm	5-15 cm	0-5 cm	5-15cm	
Control	2.8	1.3	23.3	21.6	0.27
Compost 40 m^3 ha^{-1}	7.5	3.9	62.5	65.0	0.75
Compost 80 m^3 ha^{-1}	7.6	3.7	63.3	61.6	0.52
Compost 120 m^3 ha^{-1}	12.1	5.1	100.8	85.0	0.91
Compost 160 m^3 ha^{-1}	15	7.4	125	123.4	1.21
Compost 200 m^3 ha^{-1}	17.5	8.3	145.8	138.4	1.7
Grape mark 100 m^3 ha^{-1}	15.5	6.1	129.2	101.6	0.87
Grape mark 200 m^3 ha^{-1}	21.3	9.4	177.5	156.6	1.65

The increased organic material was visually apparent at Loxton Research Centre in November 2010. The control soil had a light sandy colouration typical of the South Australian Riverland region (Figure 1), whereas the soil treated with 100 m^3 ha^{-1} grape marc in 2006 was darker and some seeds remained also there were noticeably more sub-surface roots than in the control soils (Figure 2). The profile of the soil treated with the 200 m^3 ha^{-1} composted green waste showed a dark region of organic material and increased soil carbon below 5 cm depth and, similar to soil treated with grape marc, a high density of sub-surface roots was observed (Figure 3). The soil treated with 40 m^3 ha^{-1} of composted animal waste in 2006 also developed a dark surface horizon up to about 3 cm in depth which contained a strong presence of sub-surface roots (Figure 4).

Figure 1: Profile of control soil at Loxton Research Centre in November 2010)

Figure 2: Profile of soil at Loxton Research Centre in November 2010 after treatment with 100 m^3 ha^{-1} composted grape mark in 2006.

Figure 3: Profile of soil at Loxton Research Centre in November 2010 after treatment with 200 m^3 ha^{-1} composted green recycled waste in 2006.

Figure 4: Profile of soil at Loxton Research Centre in November 2010 after treatment with 40 m^3 ha^{-1} composted animal manure in 2006.

Soluble Nutrients

The analysis of the soluble nutrients (plant available) in soil samples taken from the top 5 cm soil of plots treated with composted amendments in 2006 displayed widely ranging figures, however, in general the treated soils had greater levels of N (NH_4 and NO_3) P, K and Ca but lower Fe. It is also notable that at the LRC pH was lower where composted grape mark had been applied (Table 7).

Table 7: Analysis of soluble nutrients in soil sampled in June 2012 after treatment with composted soil amendments in 2006.

Treatment (m^3 ha^{-1})	NH_4 (mg/kg)	P (mg/kg)	K (mg/kg)	B (mg/kg)	Ca (mg/kg)	Fe (mg/kg)	Mg (mg/kg)	S (mg/kg)	NO_3 (mg/kg)	Na (mg/kg)	pH	EC	Soil Moisture
Loxton Research Centre													
Control	12	9	28	0.19	53	9.7	17	0	15	53	7.5	0.13	1.4
Animal 10	24	15	33	0.31	84	5.7	21	7.6	39	63	7.3	0.18	1.3
Animal 20	25	14	41	0.45	120	3.4	31	12	83	67	7.4	0.25	2.9
Animal 30	18	17	38	0.37	88	5.3	27	11	36	69	7.1	0.19	1.7
Animal 40	12	16	51	0.41	120	3.6	36	14	88	79	7.2	0.26	2.5
Compost 40	19	10	34	0.27	73	7.5	20	7.6	37	67	7.4	0.17	2.6
Compost 80	37	13	45	0.31	98	5.2	27	12	62	83	7.3	0.22	2.6
Compost 120	27	11	72	0.39	220	1.7	62	23	210	100	7.1	0.41	9.1
Compost 160	250	11	48	0.38	140	4.6	38	15	120	84	7.2	0.29	4.8
Compost 200	19	17	43	0.49	110	4.1	29	16	63	92	7.3	0.23	4.4
Mark 100	20	19	54	0.48	96	8.4	33	15	38	91	6.5	0.2	6.9
Mark 200	250	25	150	0.94	280	1.4	140	41	140	160	6.2	0.6	18

Loxton North

Treatment (m^3 ha^{-1})	NH_4 (mg/kg)	P (mg/kg)	K (mg/kg)	B (mg/kg)	Ca (mg/kg)	Fe (mg/kg)	Mg (mg/kg)	S (mg/kg)	NO_3 (mg/kg)	Na (mg/kg)	pH	EC	Soil Moisture
Control	32	10	41	0.12	80	6.7	0.16	5.4	31	25	7.7	0.14	5.2
Animal 40	5	13	39	0.14	77	7.9	16	7.2	24	28	7.6	0.14	5.2
Compost 40	5	8.4	37	0.12	88	7.4	17	5.9	36	28	7.7	0.15	8.5
Compost 120	13	11	38	0.18	92	7.7	17	9.4	36	31	7.6	0.15	6
Compost 200	150	14	62	0.37	120	1	25	13	52	32	7.6	0.2	8.7
Mark 200	85	10	53	0.13	79	9.1	18	5.6	28	36	7.6	0.15	7.8

6. Discussion

The beneficial effects of applying composted soil amendments to Riverland citrus orchards persist for several years and even after 7 years there are noticeable differences both visually and structurally. Unfortunately funding limitations and unplanned treatments applied to the orchards without prior consultation prevented this project achieving all its intended outcomes. However, many of the soil nutrient, yield and beneficial arthropod population parameters measured in this project were favourable where moderate to high levels of composted soil amendments were applied. In the case of the predatory mite populations, there were no significant differences as a result of the addition of low levels of composted material and the animal manure treatments compared to populations in the control soils, suggesting when lower rates are applied reapplication would be required within the 6 years that data was collected.

There was significant reduction in surface soil pH where composted grape mark was used as a soil amendment at Loxton Research Centre, but this was not evident at Loxton North. At Loxton Research Centre more grape seeds and other material persisted on the surface of the soil and was mixed into the top 1-2 cm of the soil, which may have affected the result. Sieving the soil prior to testing to remove the grape mark seeds and other bulk material may have lessened the change in pH.

The plant available nutrient levels in treated soils were also higher than in control soils. This is partially explained by nutrients added as part of the composted material, but possibly also due to the increase in microbial activity detected as part of CT06007, or possible increases in root exudate associated with the increased available soil moisture and plant health.

Where growers have undertaken application of a range of composted soil amendments to their citrus orchards they have reported a reduction in thrips pressure and reduction in pesticide application. While this is only anecdotal, and given that the seasonal variability of KCT populations is difficult to quantify with control plots, it has been a consistent message that matches the results seen is this research program.

7. Technology Transfer

Results were circulated to growers through a series of grower information days and at the 2012 Riverland Field days. Some of the results and recommendations have been discussed with individual growers at other meetings and as a result of phone enquiries. Further distribution of results was not conducted due to lack of funding that resulted from the dissolution of Compost Australia and difficulties finding alternate voluntary contribution funding.

8. Recommendations

The recommendations listed in the CT06007 (below) are supported by this project and remain unchanged.

We recommend industry:

1. Encourage growers to consider the application of compost under trees as part of their KCT IPM program, with consideration of potential water and nutrient savings.
2. Promote that where application of insecticides is necessary, newer chemistry products that are less disruptive to beneficial mites and insects be used.
3. Appraise the potential benefits to KCT biocontrol, and to citrus IPM generally, resulting from lower runoff volumes of multi-fan (lower-spray volume) spray technology.
4. Canvas the potential for inclusion of citrus orchards, where composted soil amendments are applied to soils, in future carbon credit programs.

We recommend that further research be undertaken to:

1. Quantify the potential water and nutrient savings resulting from application of composted soil amendments.
2. Transfer this research to other crops and regions which have the potential for similar economic and environmental gains. .

9. References

Baker, G., Jackman, D. J., Keller, M., MacGregor, A., & Purvis, S. (2000). Development of an Integrated Pest Management system for thrips in Citrus (Adelaide, SARDI). Horticulture Australia Final Report No CT97007. South Australia Research and Development Institute. (Sustainable Systems) Adelaide.

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