Changes in Phosphorus Status of 'Cripps' Pink' Apple Trees after Application of Mulches

W.P. Kotze[1], J.D.P. Van der Merwe[1], A.F. Nicholson[1], N.J. Taylor[2], M. Schmeisser[1] and E. Lötze[1,3]
[1] Department of Horticultural Science, Stellenbosch University, South Africa
[2] Department of Plant Production and Soil, University of Pretoria, South Africa
[3] Seconded to the Stellenbosch University by Hortgro^{Science}

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Abstract

The effect of four different mulches on fruit quality was quantified, either directly via mineral nutrient contributions or indirectly, by increasing nutrient uptake efficiency in the soil. We hypothesised that fruit nutrient levels would increase more when an organic mulch, containing nutrients, was applied to the soil, with smaller/no increases when an inorganic mulch was applied to the tree row.

In this paper, we concentrate on changes in fruit phosphorus (P) concentrations after application of five treatments: a clean cultivated control, an inorganic woven geotextile fabric, and organic mulches – compost, wood chips and a vermi-castings/wood chips combination. The trial was conducted on a commercial farm, Lourensford Estate, South Africa, from October 2008 to April 2012 – on an adjacent light, sandy and heavier, sandy-silt soil.

Mineral nutrient analyses of the soil, leaves, mulches and fruit were performed. Yield and fruit size were determined. Soil temperatures and soil water status were recorded hourly during the last two seasons. P concentrations did increase chronologically from the soil, then into leaves and then into the fruit after application of mulches that provided additional P to the soil. Sporadic increases in both leaves and fruit occurred, but could not always be related to treatment effects. The significant consistent increase of P levels of the vermi-castings treatment in the heavy soil is likely to be a combination of reduced irrigation volumes, as well as a treatment effect.

All mulches resulted in the well-established buffering of soil temperatures, soil water content and percentage soil carbon. Based on results from this study, it is not feasible to apply mulches for the sole purpose to increase P levels in the soil, leaves or fruit of established trees – although increases were noticed from time to time. In addition to water and temperature modifying effects of mulches that would differ between soil textures and depend on the mulch source, increases in P concentrations may result. As yield efficiency is still the primary factor determining income per hectare for the producer, the decrease in yield that resulted from mulching under these conditions, will still outweigh any positive contributions of mulches. It is therefore of utmost importance to first adjust irrigation volumes to a mulch treatment before the advantageous properties of mulching will be of value.

INTRODUCTION

Mulches can have a direct (adding nutrients) and/or indirect (changing soil physical, biological or chemical conditions) impact on fruit tree nutrient status. Organic mulches (Forge et al., 2002) were reported to contribute mineral nutrients, like phosphorus (P) to the soil (Mervin et al., 1995; Eneji et al., 2003; Domínguez, 2004) and over time, organic mulches can result in changes in soil cation exchange capacity (CEC) (Cadavidet al., 1998) and water holding capacity, both affecting nutrient uptake. In contrast, inorganic mulches only influence the soil environment like soil temperature (Måge, 1982) and water availability, whereby influencing biological activity associated with nutrient uptake by the roots.

Phosphorus was reported to improve fruit finish, firmness and soluble solids when trees received mono-ammonium phosphate (Raese, 1987, 1998) and also plays an indirect role in fruit quality via membrane structure and cellular energies (Bramlage et al., 1980). Fruit quality can therefore be improved by ensuring that these elements are at optimal levels in the fruit (Terblanche et al., 1980).

This study was performed to quantify the effect of four different mulches, as compared to a clean cultivated control treatment, on fruit quality, directly via mineral nutrient contributions or indirectly, by increasing P uptake efficiency in the soil through changes in the soil environment. In this paper, we concentrated on changes in fruit P after application of treatments over four consecutive seasons – hypothesising that fruit P levels will increase when an organic mulch containing P, was applied to the soil, with no significant changes in fruit P levels with an inorganic or no mulch.

MATERIALS AND METHODS

Experimental trees, 'Cripps' Pink' on M793 in established orchards planted in 1994 were selected on a commercial farm, Lourensford Estate, Somerset West, South Africa (34°2'31.29"S, 18°55'16.20"E). Treatments from October 2008 to April 2012 comprised a clean cultivated control (herbicides), an inorganic woven geotextile fabric PT110 (geotextile) (Spilo, Paarl, South Africa) and organic mulches consisting of compost (Biocircle (Pty.) Ltd., Klapmunts, South Africa), wood chips (Fred's Tree Surgery, Somerset West, South Africa) and a vermi-castings (Worm Works Purveyors (Pty.) Ltd., Simondium, South Africa)/wood chips (vermi-castings) combination. Each year in October, these mulches were applied/re-applied on four tree plots, with a tree spacing of 4 m x 1.5 m, at approximately 90 L per plot, covering approx. 4 m x 1.0 m area per plot. The geotextile was only applied once and covered the same area in the randomised complete block design. Treatments were replicated six times with buffer trees between plots. Two sites, adjacent to one another, under the same management but different soil textures were chosen to replicate the trial: a light, sandy (Tukulu) soil type versus a heavier, sandy-silt (Clovelly) soil type. Fertilizer practices and irrigation scheduling were determined commercially and not manipulated according to individual mulches. The trial irrigation volumes were reduced from January 2011 onward, when over irrigation was confirmed, replacing existing nozzles (42 L h^{-1}) with ones giving a lower delivery volume (32 L h^{-1}). Orchards were still irrigated twice weekly, for 3 h per cycle.

Mineral nutrient analyses of the soil, leaves, mulches and fruit were performed by a commercial laboratory (Bemlab Pty. Ltd., Strand, South Africa). Soil temperatures and soil water content were measured with a commercial continuous logging capacitance probe (DFM, Pniel, South Africa) on an hourly basis from 10 to 60 cm in the soil, in one plot per treatment, for both sites for the last two seasons.

Fruit was harvested from all four trees per plot. Fruit maturity and storage potential were determined at the Department of Horticultural Science, Stellenbosch University, as described in detail by Van der Merwe (2012). Average fruit size and yield was also recorded. Root growth was quantified using the grid method on one tree per treatment per annum, for both sites and is described in detail in Nicholson (2012).

Data was analysed statistically with the GLM procedure, with SAS (SAS Institute Inc., Cary, NC, USA, 2006). Differences between treatments were determined by calculating least square means and least significant differences (LSD). Significance was determined at 5% ($P<0.05$).

RESULTS AND DISCUSSION

Although the impact of mulches on soil physics and chemical properties has been studied extensively, the impact of these changes on fruit nutrient composition per se, has largely been ignored. This study attempted to quantify the impacts on the tree and more specifically, apple fruit P content.

The discussion for soil analyses will be limited to the top 10 cm in this paper. As treatments received the same commercial fertilizer application, differences in mineral elements in the top 10 cm soils were either directly due to the treatments, or indirectly by eliciting changes in the soil environment. After four seasons of treatment, significant differences between treatments were found for soil P at the heavier soil site only (Table 1). The vermi-castings treatment showed significantly higher soil P than the other treatments in 2010 and 2012 on the heavy soil type.

Mineral analyses of the source material before application (Table 2a) showed differences between organic mulches in P concentration (2009 and 2011) expected for natural variation in organic material, and explained the higher soil P in the vermi-castings treatment compared to the rest of the treatments. In Table 2b, the P concentrations of the three organic mulches is shown a year after application – encompassing the changes due to natural degradation and impact of applied granular fertilizers. Woodchips contained the lowest P levels of the three organic mulches, but could contribute P towards the soil over time in contrast with no possibility for inorganic mulches like geotextile. Higher P levels in soils that received a wood chips compared to a synthetic mulch, were also reported by Mervin et al. (1995). The geotextile treatment always showed the lowest P soil values confirming findings of Mervin et al. (1995).

The unusually high P levels in the lighter soils in 2010 and both soils in 2012, cannot be explained yet. These levels were also found in the deeper soil samples not shown here. The laboratory confirmed that there was no contamination and was satisfied with the analyses. Samples in the field were composite samples across the plots, so the possibility of bias sampling can be ruled out. There were no outliers in the data set. One year before the onset of the trial, considerable amounts of P were applied to both sites as Super-phosphate and poultry manure, were also added – this could have impact on the P levels, although usually one expects the effect to be visible already within one year of application. One other possible explanation is the contribution of mineralization of P via soil micro-organisms – which can be substantial where changes in soil temperature, moisture and organic material occur (Richardson and Simpson, 2011).

In our findings, no consistent significant differences between treatments were reported for P for either leaves or fruit (Table 2) again confirming reports by Mervin et al. (1995).

In the heavier soil site, the woodchips treatment consistently had the highest average summer and winter temperatures in the top 10 cm layer of the soil profile (data not shown), followed by the compost, vermi-castings and woodchips treatments. The geotextile and control treatments showed consistently lower average temperatures, with more fluctuating in the control than the mulch treatments. More variation in average soil temperatures between treatments, and higher average temperatures were observed in the lighter soil site, also reported by Neilsen et al. (1986). The buffering characteristics of mulches, particularly the organic mulches, were also more prominent in the lighter soil site. The organic mulch treatments, especially woodchips, had the highest average winter temperatures.

At both sites, the geotextile and the vermi-castings treatments resulted in higher or intermediate soil water levels (data not shown) compared to the other treatments; this cannot not be explained satisfactory at present.

Overall root distribution in the sandy loam site was superior to that of the heavier soil site in all of the treatments and probably directly related to higher drainage in the over irrigated situation. Fine root numbers and distribution was definitely influenced by the treatments, but did not contributed towards changes in mineral nutrients of this treatment reported in the leaves and fruit. A more detailed discussion is available in Nicholson (2012).

Significant differences between treatments were reported for P fruit levels in 2011/12 in the lighter, and 2010/11, in the heavier soil sites (Tables 3 and 4). The woodchips and vermi-castings treatments had significantly higher P levels than the control in the lighter – (2011/12) and heavier soil sites (2010/11). The vermi-castings treatment also had significantly higher soil P levels than the control treatment in the heavier soil in 2010/11, which could have contributed to the observed fruit results in 2010/11. An increase in fruit P after applying P to the soil was also reported by Cripps (1987), Raese (1998) and Neilsen et al. (2008). However, neither an increase in soil P levels or fine root numbers or distribution in these profiles (data not shown) can explain the significantly higher fruit P in the woodchips treatment, or the lack of similar results for the compost and vermi-castings treatments, in our trial. As significant differences of P in the heavy soil in 2010/11 did not prevail during the following season, or occurred at the sandier soil site, definite treatments effects on fruit P in this study cannot be confirmed.

The increasing trend for fruit P levels over the four seasons in both sites, concurred an increase in fruit size in both sites (data not shown), confirmed previous reports of this observation (Stiles, 1994) and could be due to the reduced irrigation volumes from 2008/9 to 2011/12 (P uptake is predominantly a factor of diffusion) that also stimulated overall fine root development and root distribution in the profile – resulting in increased uptake of P from the soil.

As no significant differences were found between treatments for fruit quality, results will not be shown or discussed. Generally, yield efficiency was higher in the lighter than heavier site (Table 5). Significant differences between treatments occurred during all four season, but only in the heavy soil site (data not shown). Yield efficiency was significantly higher in the woodchips than other treatments in 2009. Thereafter a significantly higher yield was recorded in the vermi-castings treatment compared to all treatments, except for the woodchips. Average yields and fruit size data over the four seasons are summarised in Table 5. Detailed discussions are available in Kotze (2012) and Van der Merwe (2012). Data will not be discussed further in this paper, as the same trend was not followed in both sites, the differences in yield efficiency was not directly due to the application of mulches or availability of P.

CONCLUSIONS

Fruit quality in apples is related to especially P concentrations of the fruit and to lesser amount, concentrations in the leaves and soil. Phosphate levels did not increase systematically from the soil, to the leaves and then to the fruit after additional P was provided to the soil with the organic mulch treatments. Sporadic increases in both leaves and fruit occurred, but these could not always be related to treatment effects. Neither was the same trend noticed in both sites, during the four seasons.

Based on results from this study, it is not feasible to apply organic mulches for the sole purpose to increase P levels in leaves or fruit of established trees – although increases were noticed from time to time. The significant consistent increase of P levels of the vermi-castings treatment in the heavy soil, is likely to be a treatment effect and may eventually result in an increase in fruit and leaves if treatment is maintained. The overall increase in soil P levels across treatments in both sites indicates the involvement of other factors not quantified in this paper, e.g., microorganism activity, and this needs to be addressed in future.

In addition to water and temperature modifying effects of mulches that would differ between soil textures and depend on the mulch source, increases in P concentrations may occur in the soil and eventually in the leaves and fruit of apple trees and therefore mineral composition in these entities should be monitored regularly to adjust fertilizer recommendations accordingly. It is of utmost importance to first adjust irrigation volumes to a mulch treatment before the advantageous properties of mulching will be of value.

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Tables

Table 1a. Changes in P concentration in the top 10 cm soil at the heavy soil site from 2008 (before treatments commenced) to 2012 (after 4 seasons of application) and % C in 2012 in response to mulch treatments and standard commercial fertilisers.

Treatment	2008	2010	2012	2012	2008	2010	2012	2012
	Heavy soil				Lighter soil			
	P mg kg-1			% C	P mg kg-1			% C
Control	30.3 ns	45.0b	81.3b	4.53ns	51.8	129.3	117.8	2.83c
Compost	28.3	39.8b	98.0b	4.53	49.5	105.8	245.3	4.90a
Geotextile	27.3	25.7b	60.0b	5.79	60.5	108.0	235.3	3.74bc
Woodchips	29.5	27.8b	53.3b	4.27	46.3	204.7	219.3	3.32bc
Vermi-castings	27.8	158a	254a	4.46	42.0	104.7	237	4.03ab
P	0.861	0.001	0.000	0.361	0.808	0.082	0.659	0.017
LSD	6.7	64.6	73.2	1.86	28.1	81.1	207.9	1.11

Data was significant at 5% level (P<0.05). Means with "ns" was not significantly different. Means with different letters within the same column differ significantly. Recommended range for apple production in sandy soil: mg kg-1 P 20-150 (P. Raath, pers. commun., 2013).

Table 1b. P concentration and % C in the top 10-30 cm and 30-50 cm soil at the in 2012 (after 4 seasons of application) in response to mulch treatments and standard commercial fertilisers.

Treatment	10-30 cm P mg kg-1	% C	30-50 cm P mg kg-1	% C	10-30 cm P mg kg-1	% C	30-50 cm P mg kg-1	% C
	Heavy soil				Lighter soil			
Control	53.3b	3.58ns	36.5b	3.83ns	68.0 ns	2.92b	46.8ns	2.69ns
Compost	56.6b	4.95	40.5b	4.34	132.8	4.90a	110.0	4.46
Geotextile	35.5b	3.97	35.0b	4.15	112.3	4.34ab	80.5	3.96
Woodchips	36.8b	4.85	31.8b	4.11	132.0	2.88b	78.8	3.09
Vermi-castings	126.5a	4.18	103.5a	4.50	119.0	3.68ab	84.3	3.57
P	0.002	0.240	0.015	0.774	0.626	0.046	0.627	0.057
LSD	41.9	1.43	42.8	1.18	100.0	1.49	84.9	1.22

Table 2a. Mineral analyses for phosphorus of the newly purchased compost and vermi-casting mulches before application in October 2008, 2009 and 2011.

Treatment	pH KCl	P %	pH KCl	P %	pH KCl	P %
	2008		2009		2011	
Compost	7.5	0.15	8.0	0.17	7.0	0.34
Vermi-casting	7.1	0.18	7.8	0.77	7.6	0.90

Table 2b. Phosphorus concentration, EC and pH analyses of the organic mulches sampled in October 2011 at both sites, one year after re-application in 2010.

Treatment	pH KCl	EC mS m^{-1}	P %	pH KCl	EC mS m^{-1}	P %
	Heavy soil site			Lighter soil site		
Compost	6.98a	87.17b	0.15b	6.72a	118.72ns	0.23ab
Wood chips	6.48b	84.92b	0.08b	5.57b	80.10	0.07b
Vermi-castings	7.15a	140.38a	0.35a	6.63a	126.90	0.39[a]
P value	0.0008	0.0023	<.0001	0.0186	0.1883	0.0314
LSD	0.28	28.75	0.08	0.82	55.94	0.23

Data was significant at 5% level ($P<0.05$). Means with "ns" was not significantly different. Means with different letters within the same column differ significantly.

Table 3. Mineral analyses for P concentrations in fruit from first harvest in April 2009, until last in April 2012, for the heavy and light soil sites.

Treatment	2009	2010	2011	2012	2009	2010	2011	2012
	Heavy soil				Lighter soil			
Control	8.07ns	5.35ns	5.60c	7.81ns	5.55ns	6.98ns	6.23ns	6.16b
Compost	6.11	9.08	7.73ab	10.81	5.50	6.62	7.20	9.45ab
Geotextile	6.32	5.61	6.53bc	8.95	5.45	6.35	5.78	8.80ab
Woodchips	6.01	6.31	7.69ab	8.19	6.64	5.92	6.58	10.11a
Vermi-castings	8.12	5.58	8.84a	9.41	5.19	6.15	6.36	12.17a
P	0.086	0.224	0.002	0.279	0.29	0.652	0.712	0.033
LSD	2.05	3.66	1.46	2.95	1.44	1.55	2.09	3.57

Table 4. Mineral analyses for P concentrations in leaves from first harvest in April 2009, until last in April 2012, for the heavy and sandy soils.

Treatment	2009	2010	2011	2012	2009	2010	2011	2012
	Heavy soil				Light soil			
Control	0.10ns	0.21ns	0.17ns	0.10ns	0.12ns	0.20ns	0.19ns	0.17ns
Compost	0.11	0.22	0.28	0.11	0.13	0.21	0.22	0.20
Geotextile	0.11	0.23	0.16	0.11	0.11	0.27	0.18	0.16
Woodchips	0.10	0.20	0.28	0.10	0.12	0.21	0.23	0.17
Vermi-castings	0.11	0.18	0.28	0.11	0.14	0.23	0.26	0.22
P	0.081	0.633	0.082	0.081	0.238	0.201	0.093	0.417
LSD	0.01	0.07	0.12	0.01	0.03	0.05	0.06	0.07

Table 5. Average yield efficiency and fruit size per treatment over four seasons.

Treatment	Yield efficiency kg fruit cm^{-1} stem circ.		Average fruit size mm	
	Heavy soil	Light soil	Heavy soil	Light soil
Control	2.9	3.6	66.8	67.3
Compost	2.8	3.8	66.5	66.9
Geotextile	3.2	4.0	66.9	66.7
Wood chips	2.8	3.5	67.0	66.3
Vermi-castings	3.4	3.6	66.4	67.3