AN EVALUATION OF THE INFLUENCE OF BIODYNAMIC PRACTICES INCLUDING FOLIAR-APPLIED SILICA SPRAY ON NUTRIENT QUALITY OF ORGANIC AND CONVENTIONALLY FERTILISED LETTUCE (*LACTUCA SATIVA* L.)

Bacchus, G.L.[1]*
[1] 30 Bennett St., Paeroa 3600, New Zealand.
* Telephone: +64 7 862 7929, Email: gillbacchus@xtra.co.nz (corresponding author)

Abstract

Evidence for the role of silica in plants is reviewed with respect to the application of silicate based sprays in biodynamic agriculture. There is research indicating improved resistance to pests, disease, drought and other stresses on plants from application of silica fertilisers and sprays. There is also evidence of improved nutrient uptake.

Experiments with field grown lettuce were undertaken to evaluate the effects of the biodynamic field-spray preparations and organic composts on lettuce yield, nutrient uptake, nitrogen metabolism, antioxidant activity and soil organism activity. Higher fresh yields of field lettuce were observed with organic composts than with a mixture of diammonium phosphate and calcium ammonium nitrate applied at similar N and P application rates.

Although lettuce yields were higher when the compost and plants were treated with biodynamically prepared silica sprays, the variation in lettuce fresh yield in the field was high (c.v. 28%) and the effects of the sprays were not statistically significant (p 0.05). Irrespective of fertiliser source, composts or soluble fertiliser, silica sprays produced lettuce at harvest (47 DAT) with higher dry matter content and crude protein in fresh leaves. However, application of silica spray had no statistically significant effect on lettuce fresh head yield, N uptake, plant sap nitrate concentrations, NO_3 to TKN ratio, and amino acid content.

Further investigation of management practises, such as the use of biodynamic field sprays, which may contribute to nutrient uptake and assimilation and improved product quality within an organic system, is recommended.

Keywords: Biodynamic; organic; compost; lettuce; light absorption; nitrate; protein; silica;

Introduction

Adoption of organic and biological systems is increasing, as farmers recognise their contribution to farming sustainability and because they can often obtain price premiums for certified organic produce. Organic producers work with whole systems. This involves many factors such as climate, improving soil conditions, and cultivation timing, rather than treating a crop independently of its surroundings. One of the reasons for adopting an organic system is that many people assume that using an organic system should lead to more nutritious plant and animal products. However, from numerous comparative research trials that measured product nutrient content, results have been very variable and inconclusive. Some reasons for this are the many factors involved in managing whole systems, including soil type, climate, planting and harvest date, all of which can affect nutritional value irrespective of farming system (Bourne, 1994). Past studies have used different methodologies; some compared the whole system of growing over a number of years, whereas many others compared different treatments of various organic and soluble fertilisers (Woese *et al*., 1997). Further consideration is needed of what management factors within a whole system might make a difference to nutritional value, and what parameters should be measured to assess this.

Bloksma *et al*. (2001) investigated many plant growth and food quality parameters in apples, and they postulated that good food quality requires integration of the growth processes that result in high yield and the differentiation processes that lead to fruit and seed production and formation of secondary metabolites (e.g., antioxidants). Most organic growers focus on growth processes through improving soil health, whereas a biodynamic system works with both these growth processes; and with the wider environmental influences of planets and stars on plant differentiation and quality.

A biodynamic system incorporates organic practises such as composting to build and maintain soil health. These are supplemented with applications of biodynamic preparations. Some of these preparations are aimed at enhancing soil organism activity: others to enhance plants' sensitivity to influences of the sun, moon, planets and stars. The art of using these preparations is to regulate the growth processes coming mainly from the soil, with the differentiation processes coming mainly through sunlight, for achieving optimum productivity and quality.

Silica (SiO_2) has traditionally been applied to plants by biodynamic growers in the form of horn-silica (preparation 501) spray[1]. Horn-silica is applied in a very dilute concentration (1g/37L/ha) of colloidal silicon dioxide as a spray above the plant; at a very low application rate compared to the more conventional amendment applications. Horn-silica is claimed to enhance flowering, ripening and flavour of products (Pettersson, 1977). However, few specific effects of the silica spray have been recorded, because it is generally only applied after the other biodynamic preparations (preparation 500 and the compost preparations[1]) have been applied to the land.

Review of research on the effects of silica on plant growth

Silicon has been applied to crops in a variety of forms and application modes, but its effects on plant growth are still debated. Fauteux *et al*. (2005) reviewed the existing evidence and concluded that silicon (Si) is not only involved in structural and physiological plant processes, but also plays an important role in plant resistance to pathogenic fungi. This role is one that has long been recognised by practitioners of biodynamic agriculture (Remer, 1995).

A considerable amount of research on the application of silica to crops has been carried out in recent years, particularly in South Africa, Australia and Asia. Much of the research has focussed on using silica to increase plant resistance to disease. Silica has been found to alleviate various stresses ranging from biotic (e.g., disease and pests) to abiotic (such as gravity and metal toxicities; Epstein, 2008). It has also been found to alleviate UV-B radiation stress (Shen, 2008). Hodson and Evans (1995) reviewed evidence that silica reduces aluminium toxicity in plants.

It is now well-established that silicon fertilisers increase yields in silicon-accumulator plants such as rice and sugarcane (Kingston, 2008). Improved yields of sugar cane and rice have been recorded after calcium silicate was applied to strongly weathered, silica-deficient soils (Berthelsen *et al*., 2001). Lynch (2008) reported that silicates have consistently outperformed high-analysis fertilizer in broadacre cereal production – measured as increased protein levels, increased yields, decreased screenings, and increased grains/head – and there are many case histories of increased quality of fruit and vegetables. There appear to have been fewer scientific trials reporting on the effects of silica on nutrient uptake and nutritional quality of crop products, particularly in dicotyledon plants. Pre-treatment of seeds, application to the soil, or spraying with a silica compound improved yield and vitamin C content of mangold (chard), daikon (Japanese radish) and lettuce (Yanishevskaya and Yagodin, 2000).

The mechanisms by which silica reduces stress in plants have been explored. Liang (2008) summarised the key mechanisms of silica mediated alleviation of water-deficit stress in higher plants as: (1) enhancement of plant growth via improved leaf photosynthesis and root activity, (2) alleviation of osmosis stress by reducing transpiration and/or improving water retention, (3) stimulation of antioxidant defence activity and reduction of lipid peroxidation, and (4) improvement of plasma membrane and tonoplast structure, integrity and vital functions. For example, Agarie *et al*. (1998) showed that application of silica in the nutrient solution reduced rate of transpiration through stomatal pores of rice leaves. Foliar application of potassium silicate stimulated antioxidant superoxide dismutase activity and increased photosynthetic capacity and chlorophyll content in bentgrass, especially under a high fertiliser regime (Schmidt *et al*., 1999).

---

[1] The biodynamic preparations have been developed from recommendations made in 1924 by Rudolf Steiner (1993). Horn-silica (Biodynamic Preparation 501) is made by grinding quartz crystals to a very fine dust, making it into a slurry with water; this is then inserted into a cow horn. The cow horn is then buried in fertile, organically-managed soil for about six months during summer (Procter, 1995). After removal from the horn, the substance is stirred in water, and then applied in early morning as a fine spray in the air over the plants to be treated.

[2] Biodynamic preparation 500 is made by filling a cow horn with fresh cow manure and burying it in soil for about six months during winter. The finished product is stirred in water, and then applied to soil or pasture in late afternoon at the rate of 65g/33litres water/ha. The compost preparations 502 to 506 are made by decomposing particular plant parts in specific animal parts, which are then buried in soil. About 1g of each of these is placed separately in a compost heap or liquid fertiliser to bring order to the decomposition process. Preparation 507 is a plant extract made from Valerian blossom juice; this is sprayed over the heap.

Further effects of silica on plant physiology that have been reported include that silicon assists the incorporation of inorganic phosphate into ATP, ADP and sugar phosphates in sugarcane (Marschner, 2002). Total amino acid concentration and the proportion of asparagine to other amino acids were higher in rice plants grown in nutrient solutions that included silicon dioxide (Watanabe *et al*. 2001). Lower sucrose concentration in phloem sap of plants grown with silica indicated that loading and/or unloading of sucrose into phloem could be affected by silica nutrition. Silicon compounds made from polycondensate boiler waste (94-96% CH_3 $SiOCl_3$), applied with nutrients in a hydroponic system, increased intensity of respiration processes, activity of oxido-reductive enzymes, and the accumulation of carbohydrates and free amino acids (the latter by over 100%) in leaves of two Arum plant varieties (Zaimenko, 1998).

Several writers have reported that silica is more effective if used in an activated form. Matichenkov and Bocharnikova (2008) tested several types of new-generation silica fertilisers that included other ingredients known to have synergic effects on the active Si, and extremely high contents of plant-available silica. A liquid complex silica fertiliser containing concentrated monosilicic acid and specific organic substances was tested on wheat in a field trial. Treatment at the time of seed planting at a rate of 0.4 L silica fertilizer per hectare (dilution 1:1000) increased the yield from 2.9 to 4.6 t/ha, and improved the quality of the wheat. Diatomaceous earth was also found to be effective.

When such activated silica is applied, lower concentrations of silica can be more effective in improving plant mineral uptake than larger concentrations. For example, Tesfagiorgis *et al* (2008) found that using doses of 1- 50 kg/ha of active Si substance on zucchini plants as seed treatment, or foliar application, was more effective than larger doses. The total accumulation of P, Ca, and Mg in plants was maximal when Si was supplied to the nutrient solution at lower rates (i.e., 50 mg ℓ-1), and extra applications had no or negative effects. However, when Si was applied at >50 mg ℓ-1, then the P level of the fruit was reduced by 50%.

It appears that there are a wide range of physiological effects of applying silica to plants, with greater improvements in mineral uptake and yield from applying small quantities of activated silica.

Biodynamic horn silica

The biodynamic horn silica, which is applied in very low concentrations, appears to act as an activated form of silica. Some of its reported effects appear to be similar to those of other silica fertilisers. For example, horn-silica spray application reduced leaf surface area, stomatal opening and transpiration rates, increased chlorophyll content, and diameter of roots, but did not affect photosynthesis rate in bush beans (Tegethoff, 1987 in Koepf, 1993). Preparations 500 and 501 applied several times together (500 in the evening, 501 in the morning) increased relative leaf surface in upper, younger leaves, reduced overall leaf area, increased net CO_2 assimilation, and reduced stomatal oscillations; but 501 only decreased CO_2 assimilation (Koenig,1988). Remer (1995) found that a D7 solution of the horn-silica preparation (nine parts of carrier mixed with one part of active substance, repeated 7 times) increased concentrations of some amino acids in Savoy cabbage, possibly by promoting the formation of enzymes responsible for acid metabolism. Application of the biodynamic preparations increased pure protein as a percentage of crude protein (by 3-5%), dry matter content and essential amino acids, particularly methionine, but reduced total crude protein content in potatoes compared to applying soluble fertilisers (Granstedt and Kjellenberg, 1996). Concentrations of essential amino acids, as constituents of total crude protein, are a well established measure of food nutritional quality (Young and Borghona, 2000). Beans grown using the biodynamic preparations contained higher levels of most amino acids, compared to beans grown hydroponically. Methionine and cysteine contents were 26.61 and 25.69 mg/g protein respectively, and their chemical scores (FAO, 1973) were 76% and 74% respectively (Stolz *et al*., 2000).

Koepf (1993) observed that plants sprayed with horn-silica spray look as though they have grown in more intense light than those not sprayed. He compared visual and compositional characteristics of such plants with plants grown in the shade and plants grown with high levels of nitrogen fertiliser. Plants grown in the shade, or with more nitrogen, had larger, more elongated leaves then plants grown in intense light or when horn silica had been applied. The ‘light-grown’ plants also had higher true protein and vitamin C content, and better taste.

Bloksma *et al*. (2001) described a similar finding from comprehensive studies of apple trees and carrots. Plant physiological processes were divided into those that promote growth and those that lead to differentiation. Applying the biodynamic field-sprays 500 and 501 favoured the differentiation processes that promote fruit, seed and secondary metabolites production. Fritz *et al*. (1997) reported that treatment with horn-silica significantly improved post-harvest storage quality of lettuce in shaded plants, but reduced storage quality of unshaded plants, with effects similar to those from gibberellin application.

Plant effects caused by foliar application of a very dilute silica spray could result from silica being assimilated by the plant, changes in light wavelengths above the plant, or from residual leaf silica causing changes in light interception by the plant. Apart from a direct effect on photosynthetic rate, light is important in triggering many plant process, e.g., white light promotes activation (dephosphorylation) of nitrate reductase, possibly through concentration of sugar phosphates in leaves, and/or by enhancing the activity of protein phosphatases, which appear to be regulated by redox control (Lillo and Appenroth, 2001). Small changes in light wavelength may also affect nitrate reductase gene expression, which affects the rate of assimilation of nitrates into more complex compounds such as amino acids. Effects through cell signalling of small changes in light absorption could explain why a very low concentration of silica, as in horn-silica spray, could affect plant physiology.

Kingston (2000) stated that it is not clear that responses to foliar applications of potassium silicate are due to 'in planta', or merely topical effects, as similar responses occur with non-Si products, and incorporation of foliar applied Si in leaf tissue is contrary to our current understanding of Si uptake, transport and deposition.

Methods: investigation of effects of biodynamic practises on plant growth and nutrient composition

Effects and possible mechanisms of the application of horn silica to plants were investigated in trials conducted in 2002-3. The experimental work was designed to determine relationships through which application of composts and biodynamic field sprays 500 and 501 could affect plant growth and nutrient composition. There was a particular focus on whether effects of the biodynamic field-spray preparation's effect on nitrogen metabolism could be detected by measuring concentrations of elements, nitrates, amino acids and antioxidants concentrations in lettuce leaf tissue.

Design and treatments

Lettuce (*Lactuca sativa* L. cv. Canasta) plants were grown in a field trial in volcanic sandy loam soil near Tauranga, New Zealand (latitude 37.7°S, longitude 176.3°E, altitude 20 m above sea level). The soil had been managed organically for at least 12 years. A factorial design with 6 treatments was used in setting up 24 plots of 1.4m x1.4m in 4 blocks. Plots were amended with composts, soluble fertilisers or no fertiliser. At seed-bed preparation, the organic (Org) and biodynamic (Bd) composts were applied at 8.3 kg/m^2 (wet weight), giving approximately 60 g/m^2 N and 4 g/m^2 P. Diammonium phosphate and calcium ammonium nitrate (treatment code DC) were also incorporated at this stage in the soluble fertiliser plots to supply the same quantities of N and P in g/m^2. No K was applied as this was already oversupplied in the soil. Plots in each amendment treatment were either sprayed (Sp) twice with biodynamic field preparation 500 at 1 and 38 days after transplanting (DAT), and three times with preparation 501 at 5, 9 and 39 DAT (sprayed plots), or they were sprayed with water at the same times (unsprayed plots). Treatments were replicated four times. At transplanting, gravimetric analysis of wet and dried soil samples indicated a soil water deficit of approximately 70mm. Seedlings were irrigated weekly to maintain the soil water deficit between 30 – 50 mm.

Measurements

Regular observations of leaf and root growth were made. At intervals, lettuce leaf nitrate concentrations were measured using Merck nitrate test strips to analyse leaf cell sap, and by Technicon autoanalyser after acetic acid extraction from dried leaf material (Prasad and Speirs, 1984). Sap was extracted from young mature leaves from two plants/plot; this was done by chopping the leaves, mashing them by using a pestle and mortar, placing them in a piece of thin polyethylene film, and then squeezing the sap through pinholes.

Roots and shoots were harvested at 28 and 47 DAT and dried and weighed. Total N and P were extracted from dried leaves by Kjeldahl digestion (McKenzie and Wallace 1954), followed by analysis using a Technicon autoanalyser (Twine and Williams, 1971). Amino acid concentrations were also measured in dried leaf material by a method similar to that of Fierabracci (1991), and using the Ferric Reducing Ability of Plasma (FRAP) assay (Benzie and Strain 1996) respectively. Measurements were made of soil microbial activity by soil respiration *ex situ* to determine relationships between treatments and soil biological activity.

Results were analysed for variance by SAS. Treatment means were compared by t- test and by Tukey's multiple comparison procedure. Residual variance was examined for normality and constant variance.

Results and discussion

High variability between plants within treatments, and small differences between treatment means for most parameters measured, prevented many statistically significant differences or relationships being found. It seems likely that there was high variability in the lettuce plants used, and soil composition variability within plots was also possibly high. In the field trial, fresh head yield at 47 DAT had a cv of 28% (Table 1). Composted plots produced significantly higher fresh head yields of lettuce than other plots; this is probably attributable to more available nitrogen being taken up between 28 and 47 DAT from composted soils. Regular soil moisture measurements indicated higher soil moisture contents in compost-treated soil. The spray appeared to have different effects on plants depending on whether they grew in composted or uncomposted treatments. After the second spraying, a growth check in sprayed plants was clearly observable; this is reflected in plant weights measured.

Table 1. Fresh weight and dry matter (DM) % of lettuce heads and roots at 28 and 47 days from transplanting (DAT). Means of 8 plants (28 DAT) and 12 plants (47 DAT) shown for each treatment.

Treatment	Plant fresh weight (g)		Head DM (%)		Root DM (%)	
	28 DAT	47 DAT	28 DAT	47 DAT	28 DAT	47 DAT
Ctrl (n = 4)	28.9 cd	202.8 bc	6.2 b	6.0 ab	6.6 ab +	9.9 a
C + sp	22.3 d	174.2 c	7.4 a	5.9 b	7.5 ab	10.8 a
DC	36.8 bc	214.9 bc	6.4 b	5.3 c	6.9 ab	11.8 a
DC + sp	27.4 cd	160.2 c	7.2 a	6.4 a	8.4 a	11.9 a
Org	43.8 ab	279.4 ab	6.2 bc	5.6 bc	6.6 ab	10.4 a
Bd	47.4 a	315.1 a	5.5 c	6.0 ab	6.3 b	10.6 a
Fertiliser						
None (n = 8)	25.6 b	188.5 b	6.8 a	6.0 a	7.1 a	10.4 b +
DC	32.1 b	187.6 b	6.8 a	5.9 a	7.7 a	11.9 a
Compost	45.6 a	297.2 a	5.8 b	5.8 a	6.5 a	10.5 ab
Spray*						
No sprays	32.8 a	208.8 a	6.4 b	5.7 b	6.8 a	10.9 a
Sprays (n =8)	24.8 a	167.2 a	7.4 a	6.1 a	8.0 a	11.4 a

Treatment codes: Ctrl = Control, C+sp = Control + biodynamic field sprays, DC = soluble fertilisers DAP + CAN, DC + sp = soluble fertilisers + Bd field sprays, Organic (Org) = compost, Biodynamic (Bd) = biodynamic compost +sprays

* Means of control and DC treatments only

Different letters indicate significant difference by t-test at 0.05% level. + indicates significant difference by Tukey test at 0.05% level.

At 28 DAT the percentage NO_3-N of dry lettuce leaves was significantly higher for the compost treatment than other treatments. This difference was absent just prior to harvest at 47 DAT (Table 2), and was not apparent in the sap values measured (Merck strip) at 39 and 45 DAT; however, the Merck-strip NO_3 value was higher in the DC treatment at 39 DAT. Neither test (Merck strip nor acetic acid) demonstrated any effects of sprays on the nitrate content of lettuce leaves at or near harvest (45 – 47 DAT). There was poor correlation between NO_3 determined by acetic-acid extraction of dried leaves and Merck-strip analysis of fresh-leaf cell sap. The acetic-acid extraction, however, did show that the lower nitrate concentration in sprayed plants at 28 days was significant, but this difference was again not evident at 47 DAT.

Table 2. Mean nitrate concentrations in leaf sap 39 DAT at 7pm (Merck strip) and in dried leaf material of field grown lettuces at 28 and 47 DAT and nitrate N: total N ratios Treatment codes as for Table 1.

Treatment	NO_3 mg/l in cell sap (Merck strip)		%NO_3-N in dry leaves (acetic acid extracted)		NO_3-N :tot TKN*	
	39 DAT	45 DAT	28 DAT	47 DAT	28 DAT	47 DAT
Ctrl	633.3 ab	825.0 a	0.20 a	0.14 a	0.05 a	0.04 a
C + sp	433.3 c	850.0 a	0.15 b	0.19 a	0.04 bc	0.05 a
DC	700 a	1050.0 a	0.18 ab	0.20 a	0.05abc	0.05 a
DC + sp	600 ab	975.0 a	0.13 b	0.18 a	0.04 c	0.05 a
Org	500 bc	900.0 a	0.21 a	0.18 a	0.05 ab	0.05 a
Bd	533.3 bc	875.0 a	0.23 a	0.14 a	0.06 a	0.04 a
Fertiliser						
Control	533.3 b	837.5 a	0.17 b	0.17 a	0.05 ab	0.04 a
DC	650 a	1012.5 a	0.16 b	0.19 a	0.04 b	0.05 a
compost	516.7 b	887.5 a	0.22 a+	0.16 a	0.05 a	0.04 a
Spray**						
No sprays	666.7 a	937.5 a	0.19 a	0.17 a	0.05 a	0.05 a
Sprays	516.7 a	912.5 a	0.14 b	0.19 a	0.04 a	0.05 a

* Calculated from acetic acid extraction results
** Means of control and DC treatments only
Different letters indicate significant difference by t-test at 5% level.
+ indicates significant difference by Tukey test at 5% level*

The ratio of NO_3 to TKN in dried leaf material (Table 2) provides an indication of relative difference between rates of nitrate uptake and rates of assimilation of nitrate into amino acids, protein and other nitrogenous compounds. No fertiliser or spray treatment caused any significant differences in the proportion of N present as NO_3 in lettuces at final harvest (47 DAT). The high variability between nitrate and total-N concentrations in individual plants within treatments meant that differences between treatment-ratio means would have to exceed 0.017 (47% of the lowest treatment mean) for a significant result to have been found. As the soil was initially high in NO_3, lettuces of all treatments may have taken up nitrate preferentially to ammonium, and most plants contained high concentrations of nitrate.

Compost treatments took up significantly more N than the control and DC treatments between 27 – 47 DAT. Plant percentage TKN was converted to g crude protein/100g fresh leaves, and sprayed plants appeared to contain significantly more protein than unsprayed plants. This significant difference is generated by small treatment differences in plant dry weight: fresh weight ratio (Table 3). Total N percentage (Kjeldahl N – not including NO3 –N, TKN) of leaf dry matter was significantly higher in lettuce plants from compost treated plots at 28 DAT (Table 3); however, by 47 DAT there were no significant differences between treatments in total percentage N.

Table 3. Nitrogen and protein content of lettuce leaves at 28 and 47 DAT. Treatment codes as for Table 1.

Treatment	**% TKN (dry wt)**		**N uptake (mg/plant/day)**	**Protein content (mg/100g fresh wt)**	
	28 DAT	47 DAT	28-47 DAT	28 DAT	47 DAT
Control	3.81 abc	3.75 a	16.91 ab	1.47 ab	1.40 ab
C + sprays	3.55 c +	3.99 a	16.12 ab	1.62 a +	1.47 a
DC	3.85 abc	3.84 a	14.53 b	1.54 ab	1.27 c
DC + sp	3.58 bc	3.84 a	13.77 b	1.61 a+	1.48 a
Org	4.09 a +	3.81 a	20.69 ab	1.57 ab	1.34 bc
Bd	4.01 ab	3.77 a	26.11 a	1.43 b +	1.38 abc
Fertiliser					
None	3.68 b	3.87 a	16.51 ab	1.55 a	1.44 a
DC	3.71 b	3.84 a	14.15 b	1.57 a	1.38 a
Compost	4.05 a +	3.79 a	23.40 a	1.50 a	1.36 a
Spray*					
No sprays	3.83 a	3.79 a	15.72 a	1.51 a	1.34 b
Sprays	3.561 a	3.91 a	14.94 a	1.62 a	1.47 a

*Means of control and DC treatments only.
Different letters indicate significant difference by t-test at 0.05% level. + indicates significant difference by Tukey test at 0.05% level.

P uptake between 28 and 47 DAT was significantly higher for lettuce plants in the Bd treatment than those in both DC treatments (Figure 1 and Figure 2). This related well to the greater root mass measured in the Bd treatment. The cause of the higher P uptake in the Bd treatment requires further investigation, as the effect is not a simple effect of spray application; this is because differences in P uptake compared for sprays vs. non-sprays (grouped treatments) were not significant. It is possible that some interaction between composts and sprays produced the higher P uptake in the Bd treatment. It is likely that P mineralisation by soil organisms enabled more P uptake in the Bd treatment, whereas added inorganic P may have been made non-plant available by sorption onto soil surfaces, or the added P (DC) may have inhibited the quantity of net P mineralisation.

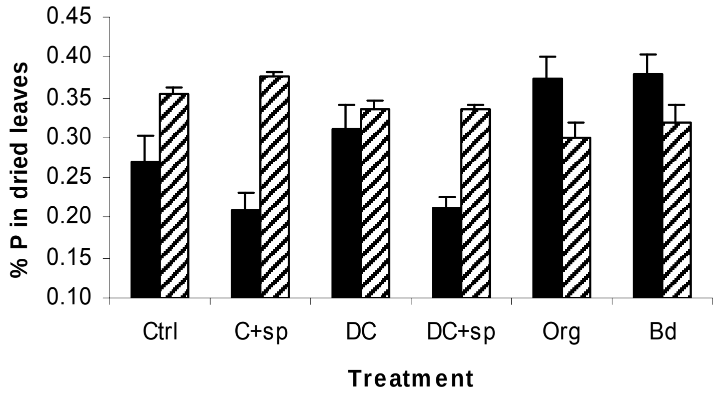

Figure 1. Percentage P in leaf dry matter for field lettuces harvested at 28 (■) and 47 (▨) days after transplanting. Error bars represent standard error of means. Treatment codes are shown in Table 1.

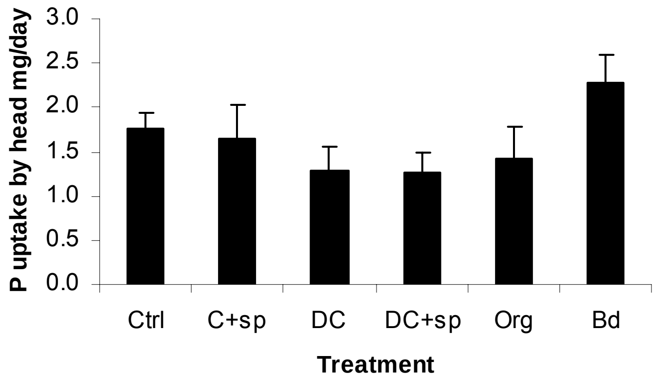

Figure 2. Phosphorus uptake by lettuce head (mg P per day per plant head) for the growth period between 28 – 47 days after transplanting. Error bars represent standard error of means. Treatment codes are shown in Table 1.

Analysis of amino acid concentrations in leaves was not carried out on sufficient replications to show any significant differences (Figure 3). The apparent 10 - 20% higher concentrations of amino acids in silica-treated lettuce plants were lower than the 25 – 100% differences in amino acid concentrations between Savoy cabbages sprayed or not sprayed with a D7 solution of preparation 501 recorded by Remer (1995). Higher amino-acid levels, such as for arginine and histidine (6 times and 2.3 higher respectively), were found by Zaimenko (1998) after treating *Anthurium* plants with a boiler-waste silica compound. Amino-acid concentrations in trial lettuce plants were similar to the values reported in the USDA amino- acid content database for lettuce (Figure 3). Further investigation is needed to establish to what extent the silica spray might affect nitrogen assimilation and metabolism in plants.

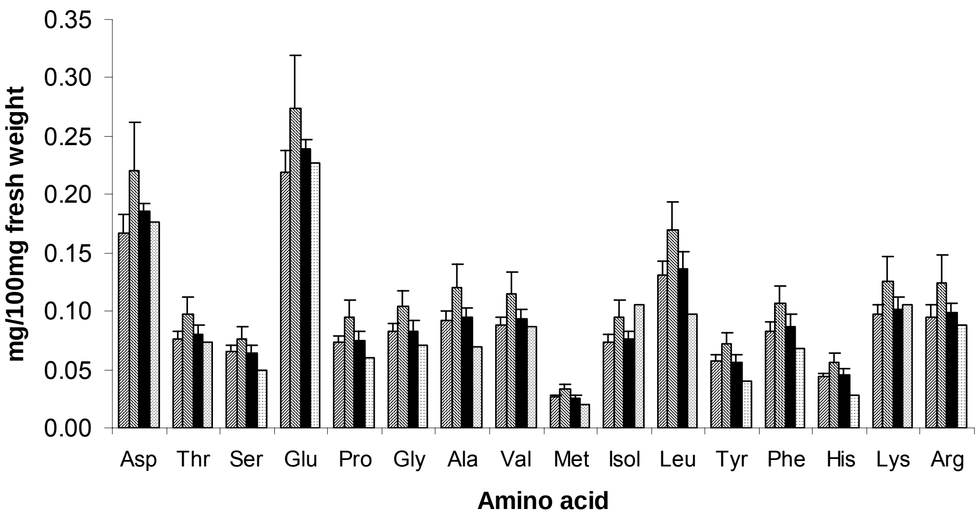

Figure 3. Amino acid content of freeze-dried field grown lettuce leaves on a fresh weight basis. Treatments DC ( ), Control + sprays ( ), Biodynamic ( ), Romaine variety, USDA database ( ). Error bars represent standard error of means.

Soil microbial activity, measured by soil respiration *ex situ* at 28 DAT, was highest in composted plots and lowest in sprayed plots (Figure 4).

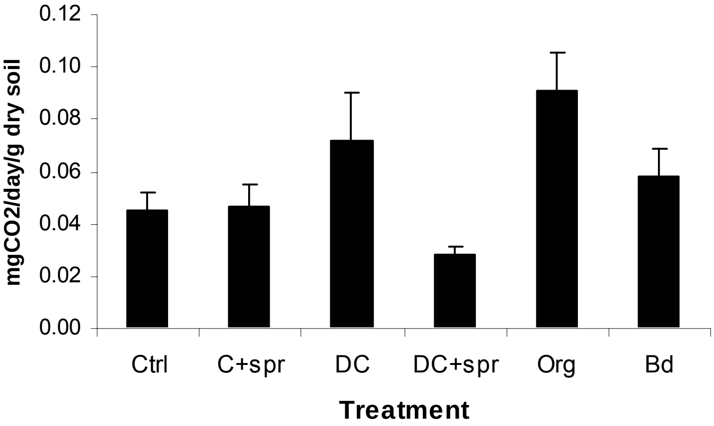

Figure 4. Carbon dioxide respiration in soil samples taken from each plot 28 days after transplanting. Bars represent standard error of means. Treatment codes shown in Table 1.

Conclusions

There is now a large body of research indicating improved resistance to pests, disease, drought and other stresses on plants from the application of silica fertilisers and sprays. There is also evidence of improved nutrient uptake.

Higher fresh yields of field lettuce were observed when a volcanic sandy loam was fertilised with organic composts than with a mixture of diammonium phosphate and calcium ammonium nitrate, applied at similar N and P application rates. Although lettuce yields were higher when the compost and plants were treated with biodynamically prepared silica sprays, the variation in lettuce fresh yield in the field was high (coefficient of variation = 28%), and the effects of the sprays were not statistically significant. Irrespective of fertiliser source (composts or soluble fertiliser), silica sprays produced lettuce with higher dry matter content; but the application of silica spray had no statistically significant effect on lettuce fresh head yield, N uptake, plant - sap nitrate concentrations and amino-acid content.

The challenges of high variability encountered when conducting trials with living plants and soil are increased when attempting to make trials relevant to a whole systems context. However, further investigation in this area would assist the debate about whether there are nutritional and health advantages from eating organic produce. No progress can be made in this debate unless the management factors that could contribute to such an advantage can be identified and measured. The concept of identifying practises that integrate growth and differentiation processes in plants introduced by Bloksma *et al.* (2001) is relevant to the question of how plant nutrient uptake and assimilation can be regulated within an organic system to optimise product quality. In view of the increasing evidence of benefits from application of activated silica to crops, the effects of application of biodynamic field sprays should be further investigated. In any such investigation, interactions between foliar treatments, plant metabolism, and plant interface with soil and soil organisms need to be taken into account.

Acknowledgements

Assistance with experimental work and analysis by Prof Mike Hedley and the late Dr Neil Macgregor at Massey University Soil and Earth Sciences Department is gratefully acknowledged.

References

Agarie, S., Uchida, H., Agata, W., Kubota, F., Kaufman, P. B. 1998. Effects of silicon on transpiration and leaf conductance in rice plants (*Oryza sativa* L.). Plant Production Science 1(2): 89-95.

Benzie, I. F. F., Strain J. J. 1996. The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": the FRAP assay. Analytical Biochemistry 239 (1): 70-76.

Berthelsen, S., Hurney, A., Kingston, G., Rudd, A., Garside, A. L., Noble, A. D. 2001. Plant cane responses to silicated products in the Mossman, Innisfail and Bundaberg districts. Hogarth, D. M. (Ed.).Proceedings of the 2001 Conference of the Australian Society of Sugar Cane Technologists held at Mackay, QLD, Australia, 1st-4th May 2001: 297-303.

Bloksma, J., Northolt, M., Huber, M. 2001. Parameters for apple quality and an outline for a new quality concept. Louis Bolk Instituut, Publ. No. FQH 01.

Bourn, D.M. 1994. The nutritional value of organically and conventionally grown food – is there a difference? Proceedings of the Nutrition Society of New Zealand 19: 51 – 57.

Epstein, E. 2008. Silicon: its manifold roles in plants. Silicon in Agriculture 4th International Conference Port Edward, South Africa. P. 37.

Fauteux, F., Remus-Borel, W., Menzies, J. G. Belanger, R. R. 2005. Silicon and plant disease resistance against pathogenic fungi. FEMS Microbiology Letters 249 (1): 1-6.

Fierabracci, V., Masiello, P., Novelli, M., Bergamin, E. 1991. Application of amino acid analysis by high-performance liquid chromatography with phenyl isothiocyanate derivatisation to the rapid determination of free amino acids in biological samples. Journal of chromatography 570: 285-291.

Fritz, J., Meyer-Glitza, P., Weidringer, A., Kopke, U., Schuler, C. 1997. Basic studies on the plant treatment preparation horn silica. [German]. Schriftenreihe - Institut fur Organischen Landbau 4: 231-237.

Granstedt, A.G., Kjellenberg, L. 1996. Quality investigations with the K-trial, Jaerna and other Scandinavian fertilization experiments. In: Raupp J. (Ed.) Quality of plant products grown with manure fertilization. Proceedings of the fourth meeting Fertilisation systems in organic farming in Juva, Finland. Institute for Biodynamic Research (Darmstadt) 9: 3-12.

Hodson, M.J., Evans, D.E. 1995. Aluminium /Silicon interactions in higher plants. Journal of Experimental Botany 46 (2): 161 – 171.

Kingston, G. 2008. Silicon fertilisers: requirements and field experiences. Silicon in Agriculture 4th International Conference Port Edward, South Africa. P. 52.

Koenig, U.J. 1988. Investigation of phenomena of diurnal rhythms and developmental dynamics with selected crops after application of biodynamic spray preparations. PhD Thesis, University of Goettingen, Germany.

Koepf, H.H. 1993. Research in biodynamic agriculture: methods and results. Bio-Dynamic Farming and Gardening Association Inc., Kimberton, PA.

Liang, Y.C. 2008. Effect of silicon on growth and tolerance to stressful environments and plant diseases in higher plants including protein and oil-bearing crops. Silicon in Agriculture 4th International Conference Port Edward, South Africa. P. 62.

Lillo, C., Appenroth, K. J. 2001. Light regulation of nitrate reductase in higher plants: which photoreceptors are involved? Plant Biology 3(5): 455-465.

Lynch, M. 2008. Silicates in contemporary Australian farming: a 20-year review. Silicon in Agriculture 4th International Conference Port Edward, South Africa. P. 68.

Marschner, H. 2002. Mineral nutrition of higher plants. Academic Press, London.

McKenzie, H.A., Wallace, H.S. 1954. The Kjeldahl determination of nitrogen: a critical study of digestion conditions-temperature, catalyst and oxidizing agent. Australian Journal of Chemistry 7: 55-70.

Pettersson, B.D. 1977. A comparison between conventional and bio-dynamic farming systems as indicated by yields and quality. Bio-Dynamics 124: 19-27.

Prasad, M., Spiers, T. M. 1984. Evaluation of a rapid method for plant sap nitrate analysis. Communications in Soil Science and Plant Analysis 15 (6), 673-679.

Procter, P., Cole G.L. 1997. Grasp the Nettle. Random House, Auckland, NZ.

Remer, N. 1995. Laws of life in agriculture. Trans. Castellitz K., Davies B. Bio-Dynamic Farming and Gardening Association Inc. Kimberton, PA.

Schmidt, R. E., Zhang, X., Chalmers D. R. 1999. Response of photosynthesis and superoxide dismutase to silica applied to creeping bentgrass grown under two fertility levels. Journal of Plant Nutrition 22(11), 1763-1773.

Steiner, R. 1993. Agriculture. A series of lectures given in 1924. Gardner, M. (Ed.). Translated by Creager, C.E., Gardner, M. Bio-Dynamic Farming and Gardening Association Inc., Kimberton, PA.

Stolz, P., Stube, J., Buchmann, M., Hiss, C. 2000. Better dietary protein-quality of beans cultivated biodynamically than by hydro-culture. In: Alföldi, T., Lockeretz, W., Niggli, U. (Eds.). IFOAM 2000: the World grows organic. Proceedings of the 13th International IFOAM Scientific Conference vdf Hochschulverlag AG an der ETH Zurich. Pp. 302 -303.

Technicon 1976. Industrial methods for NH_3-N and TKN extract analysis. No. 329-74 W/A. Technicon Industrial Systems. Tarrytown, NY.

Tegethoff, M. In: Koepf, H.H. 1993. Research in biodynamic agriculture: methods and results. Bio-Dynamic Farming and Gardening Association Inc., Kimberton, PA. P. 48.

Tesfagiorgis, H.B., Laing, M.D., Morris, M.J. 2008. Uptake and distribution of silicon on zucchini and zinnia and its interaction with other elements. Silicon in Agriculture 4th International Conference Port Edward, South Africa. P. 101.

Twine, J.R., Williams, C.M. 1971. The determination of phosphorus in Kjeldahl digest of plant material by automated analysis. Communications in Soil Science and Plant Analysis 2: 485-489.

Watanabe, S., Fujiwara, T., Yoneyama, T., Hayashi, H. 2001. Effects of silicon nutrition on metabolism and translocation of nutrients in rice plants. In: Horst W.J. et al. (Eds.) Plant nutrition-Food security and sustainability of agro-ecosystems. Pp. 174-175. Kluwer Academic Publishers, Dordrecht, Netherlands.

Woese K., Lange, D., Boess, C., Boegl, K.L. 1997. A comparison of organically and conventionally gown foods – results of a review of the relevant literature. Journal of Science of Food and Agriculture 74: 281 – 293.

Yanishevskaya, O. L., Yagodin, B.A., 2000. Effect of Si, Mn and Cr on the productivity and product quality of vegetable crops. [Russian]. Agrokhimiya. 2000. No. 5: 47-51.

Young, V. R., Borgonha, S. 2000. Nitrogen and amino acid requirements: the Massachusetts Institute of Technology amino acid requirement pattern. Journal of Nutrition, 130 (7S): 1841S-1849S.

Zaimenko, N.V. 1998. Effect of organosilicon preparation on activity of redox processes and content of some assimilates in plant leaves. Fiziologiya i Biokhimiya Kul'Turnykh Rastenii, 30: 5.