Can differences in *Cirsium arvense* and *Rumex obtusifolius* densities within pastures be explained by soil parameters?

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Abstract Some organic farming literature suggests that the presence of weeds in pastures can be explained by problems with the soil. Sixty 1 m^2 patches of pasture with different densities of broad-leaved dock (*Rumex obtusifolius*) were identified across six different paddocks on an organic dairy farm. Various soil parameters were measured in each patch to determine if any of these correlated well with the differing weed densities. Parameters measured included soil pH, moisture, compaction and concentrations of 12 nutrients in adjacent perennial ryegrass. This process was repeated for Californian thistle (*Cirsium arvense*) using a different series of 60 patches. Significant correlations were found between dock density and pH, potassium, magnesium and manganese, and Californian thistle density was significantly correlated to soil pH and sulphur content. However, these correlations were generally weak and are not considered good indicators of whether these weed species would thrive within this particular farm.

Keywords broad-leaved dock, Californian thistle, pasture weeds, soil pH, soil minerals, indicator species.

INTRODUCTION

During the 10-year organic dairy farm trial conducted at Massey University in Palmerston North (Harrington et al. 2012), field days were frequently held to report results of the work to interested farmers. A number of organic farmers and advisors commented at such meetings that the presence of weeds in pastures could be explained by problems with the soil, especially soil compaction, soil pH and incorrect nutrient levels. Presumably some of these views came from books readily available to farmers such as the one written by Pfeiffer (1970), which lists many of the weed species found in agriculture and states what the presence of these weeds tells a farmer about the soil.

Such books are often anecdotal in nature with little if any scientific trial results to back up the claims. However, scientific literature does exist that discusses indicator plants. Holzner (1982) provided one of the better reviews of literature on the subject, and concluded that some weed species are more likely to be found in soils with certain characteristics. However, he found that the relationship is seldom a good one due to complex interactions between optimal conditions for species, competitive pressures from other species and the impact of various management practices.

Broad-leaved dock (*Rumex obtusifolius*) is a very common weed in New Zealand dairy pastures, though densities can vary markedly between and within paddocks. Pfeiffer (1970) claimed that docks were more likely to be found in acidic soils that were poorly drained, usually with a hard pan impeding drainage. Boas (1958) considered it actually prefers neutral pH soils but can tolerate acidic soils. Rothmaler (2009) claimed the presence of broad-leaved dock in pastures indicates high nitrogen levels and over-fertilisation in general, as well as trampling and disturbance of the site. Bohner (2001) stated it would grow best in soils high in nitrogen, potassium and sulphur, but not soil high in calcium or sodium.

Californian thistle (*Cirsium arvense*) is claimed to prefer productive, nutrient-rich fields (Rothmaler 2009), well aerated, deep, moist soils, and to avoid very dry conditions or high water tables (Anderson 1999). Pastures on soils with adequate levels of nitrogen and potassium are associated with this species, whereas the phosphorous levels can often be quite low (Hopkins & Green 1979).

The objective of this research was to determine if correlations could be found between the density of these two species within organic dairy pastures and the concentration of nutrients, pH, moisture content and compaction of the soil. If such correlations could be found, it might offer insights into how to manage these weed species in the absence of herbicides.

MATERIALS AND METHODS

In October 2010, six paddocks with different densities of broad-leaved dock were identified on the organic dairy farmlet at Massey University. This farmlet was located near Palmerston North and had been run using organic farming principles since August 2001 (Harrington et al. 2012). The soil on the farmlet is Tokomaru silt loam and the pastures were predominantly perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). There were few differences between the pastures in the studied paddocks as all had been established for a number of years and were reasonably dense. Weed composition in pastures found on this farmlet have been studied extensively in the past (Harrington et al. 2012). In each of the paddocks, ten fixed quadrats were established, each 1.0 m^2 in size, that varied in density of broad-leaved dock plants. This gave 60 quadrats in total, with about 20 having high densities, 20 with medium densities and the remainder with low densities or no docks present at all. Two pegs were used to mark diagonal corners of each quadrat and detailed maps were made of the locations. This process was then repeated for Californian thistle, although the six paddocks used for this species were not all the same as those used for the dock trial.

Once the quadrats were established, the density of the species being studied was measured in December 2010 and again in December 2011 after all measurements of soil parameters had been completed. Two estimates of plant density were made for each species, with plants per quadrat counted and also leaves per quadrat estimated to account for differences in size of plants.

To estimate the relative level of soil macronutrients and micronutrients within each quadrat, their concentrations were measured within perennial ryegrass growing within each quadrat. By measuring relative differences between quadrats in foliar nutrient concentrations, it helped overcome issues of interpreting whether differences that might have been obtained using soil tests accurately reflect availability of these nutrients to the plants (Munson & Nelson 1990). During December 2010, 100 g (fresh weight) samples of perennial ryegrass growing in each quadrat were collected when pasture mass was between 1800 and 2200 kg DM/ha. Fertiliser had last been applied to all paddocks in May 2010 with 1.5 t/ha of composted chicken manure (Osflo). Samples were frozen in air-tight plastic bags until all samples had been collected. The material was then dried to 65°C and sub-samples were finely ground prior to the mineral composition being determined by Analytical Research Laboratories Ltd in Napier. They used a CEM Corporation closed vessel microwave to digest 0.5 g samples of dried plant tissue with 5 ml of concentrated nitric acid and 3 ml of hydrogen peroxide at a maximum temperature of 210°C. The resulting solution was diluted to 25 ml in reverse osmosis

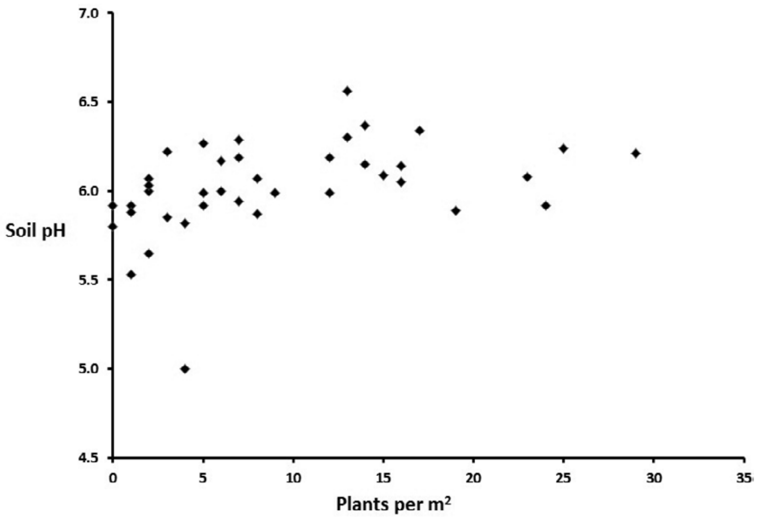

Figure 1 The relationship between soil pH within each quadrat in November 2011 and the density of broad-leaved dock in the quadrat in December 2011 (r = 0.38).

water and analysed with an inductively coupled plasma spectrophotometer. Results were compared against a linear series of standard solutions of increasing concentration.

The pH of soil in each quadrat was estimated by extracting four soil cores (2.5 cm diameter, to a depth of 7.5 cm) from each quadrat in November 2011. The samples were dried at room temperature and mixed together before sieving to a maximum soil particle size of 2 mm. Then 10.0 g sub-samples were added to 25 ml of reverse osmosis water, stirred and allowed to settle several times before being measured with a recently calibrated pH meter that was also checked at times against soil samples of known pH values.

In a cursory evaluation of drainage status and the ability of soil within each quadrat to store available water, the soil moisture content of quadrats was measured on 23 August 2011 when the ground was wet, and again on 2 December 2011 when the ground was becoming quite dry. Measurements were made using time domain reflectrometry with probes estimating the volumetric water content of the soil to a depth of 15 cm.

The soil compaction was measured using a Bush soil penetrometer, which gave estimates of soil penetration resistance at 2 cm intervals from depths of 1 cm to 17 cm. Measurements were made in all quadrats on 1 September 2011 when the soil was quite wet, then again on 8 December 2011 when the soil was becoming quite dry. Although 60 quadrats of each species were monitored, soil pH, moisture content and compaction were measured for just the 20 quadrats with the highest densities and 20 quadrats with the lowest densities of each species to reduce work-load.

Pearson correlation coefficients were calculated using SAS for the relationship between each of the soil parameters measured and each of the estimates of plant density for both broad-leaved dock and Californian thistle, with data pooled from the different paddocks used.

RESULTS

The correlation between most of the soil parameters measured and the various estimates of plant density was generally poor for both broad-leaved dock (Table 1) and Californian thistle (Table 2). However, there did appear to be a relationship between soil pH and plant density for both species. For broad-leaved dock, soil pH measurements made in November 2011 had a significant positive correlation with plant density (Pearson correlation coefficient (r) of 0.38, P=0.017, Figure 1) and leaf number (r = 0.33, P=0.039) measured several weeks later, and also with dock leaf number measured

Table 1 The Pearson correlation coefficients for the relationship between estimates of broad-leaved dock density in quadrats (leaf number and plant number at start and end of the experiment) and various soil parameters (nutrient level, moisture, pH and compaction). Coefficients in bold and underlined are significant at P<0.05.

	Number / m^2 (Dec 2010)		Number / m^2 (Dec 2011)	
Soil parameter	Leaves	Plants	Leaves	Plants
Soil pH	**<u>0.43</u>**	0.29	**<u>0.34</u>**	**<u>0.38</u>**
Nutrients:				
nitrogen	0.18	0.19	0.21	0.08
phosphorous	-0.17	-0.05	-0.20	-0.16
potassium	**<u>0.37</u>**	**<u>0.37</u>**	**<u>0.38</u>**	**<u>0.30</u>**
sulphur	-0.22	-0.14	-0.29	**<u>-0.35</u>**
calcium	-0.08	-0.16	-0.09	-0.10
magnesium	**<u>-0.31</u>**	**<u>-0.30</u>**	-0.19	-0.24
sodium	-0.04	-0.09	-0.01	0.09
iron	0.17	-0.02	0.24	0.05
manganese	**<u>-0.33</u>**	**<u>-0.39</u>**	-0.30	-0.30
copper	-0.11	-0.03	-0.28	-0.21
zinc	0.13	0.11	-0.01	-0.04
boron	-0.13	-0.17	0.05	-0.08
Moisture on:				
23 Aug 2011	0.11	0.04	0.13	0.15
2 Dec 2011	0.12	0.18	0.19	0.23
Compaction:				
1 Sept 2011: 1–7 cm	-0.08	-0.03	-0.11	0.07
1 Sept 2011: 9-15 cm	-0.07	-0.02	0.10	0.08
8 Dec 2011: 1-7 cm	0.15	0.17	0.12	0.12
8 Dec 2011: 9-15 cm	0.20	**<u>0.31</u>**	**<u>0.32</u>**	0.25

11 months earlier (r = 0.42, P=0.0065). Likewise, there was a strong positive correlation between soil pH and Californian thistle density in December 2010 both for plant number (r = 0.50, P=0.0010) and leaf number (r = 0.49, P=0.0013), but this correlation was not evident in December 2011.

With broad-leaved dock, there was also a significant positive correlation between plant density and potassium levels in perennial ryegrass plants growing within the quadrats, which was a surrogate measure of potassium levels within the soil of the quadrats (Table 1). This relationship could be seen for density measurements made in both December 2010 (just before the analyses were conducted) and in December 2011 (11 months later). Likewise, significant negative correlations were found between dock numbers and levels of magnesium and manganese in December 2010, but the correlations were slightly weaker in December 2011. A negative correlation between docks and sulphur levels became more evident in December 2011. Although the correlation between dock numbers and most other soil parameters measured were not significant, a significant positive correlation was detected with soil compaction at 9-15 cm depth measured in December 2011.

Apart from the relationship with soil pH, the only other correlation consistently detected for Californian thistle appeared to be a negative correlation with sulphur concentration, which was detected in both years of plant density measurements (Table 2). Although a positive correlation to iron concentrations was detected in the first year, the correlation was negative in the following year.

DISCUSSION

The objective of this research was to examine if variability in densities of these two weed species within a farm could be explained by differences in the soil within and between pastures. Variability in soil parameters does occur within pastures due to differences in management, deposition of dung and urine, small differences in topography with hollows and ridges, and differences in treading damage.

The main soil factor that appeared to be correlated to differences in plant density was pH. As can be seen in Figure 1, the pH in most quadrats varied from 5.5 up to 6.5, and there was a slight trend for quadrats with higher pH to have more dock plants. However, this graph also shows that a correlation coefficient of 0.38, although considered statistically significant, is still not a strong relationship. If a patch of dense docks was located, it was not possible to conclude that the soil in that patch had a higher pH than elsewhere. The correlation for any of the other factors was generally not much higher than 0.38, showing that broad-leaved dock and Californian thistle could not be considered as "indicator species" on this farm for any of the measured parameters.

A positive correlation between broad-leaved dock and soil pH contrasts with the claims of Pfeiffer (1970). However, he also considered it more likely that docks would grow in soils

Table 2 The Pearson correlation coefficients for the relationship between estimates of Californian thistle density in quadrats (leaf number and plant number at start and end of the experiment) and various soil parameters (nutrient level, moisture, pH and compaction). Coefficients in bold and underlined are significant at P<0.05.

	Number / m^2 (Dec 2010)		Number / m^2 (Dec 2011)	
Soil parameter	Leaves	Plants	Leaves	Plants
Soil pH	**<u>0.49</u>**	**<u>0.50</u>**	0.08	0.08
Nutrients:				
nitrogen	-0.07	-0.09	-0.05	-0.11
phosphorous	-0.01	0.01	-0.28	-0.24
potassium	0.07	-0.03	0.16	0.15
sulphur	**<u>-0.26</u>**	-0.17	**<u>-0.37</u>**	**<u>-0.39</u>**
calcium	-0.14	0.09	-0.10	-0.09
magnesium	-0.23	-0.07	0.17	0.17
sodium	-0.24	-0.02	-0.11	-0.14
iron	**<u>0.32</u>**	0.17	-0.22	-0.22
manganese	0.10	-0.00	-0.28	-0.29
copper	-0.14	-0.08	-0.24	-0.28
zinc	0.13	0.07	-0.06	-0.10
boron	-0.19	-0.08	-0.16	-0.19
Moisture on:				
23 Aug 2011	0.13	0.06	0.07	0.07
2 Dec 2011	-0.20	-0.24	0.11	0.11
Compaction:				
1 Sept 2011: 1–7 cm	0.11	0.06	-0.01	0.05
1 Sept 2011: 9-15 cm	-0.21	-0.13	-0.05	-0.05
8 Dec 2011: 1-7 cm	-0.07	-0.03	-0.06	-0.08
8 Dec 2011: 9-15 cm	-0.12	-0.09	-0.06	-0.07

where a hard pan impedes drainage. A positive correlation was found in the present study between dock density and higher penetrometer readings recorded below a depth of 7 cm. The penetrometer readings at that depth varied from 823 to 1939 kPa. This did not appear to lead to a significant correlation between dock densities and moisture content when wet (volumetric water contents in August 2011 ranged between 42.4% and 59.4%).

The correlation between dock density and potassium agreed with claims by Bohner (2001), although the relationship with nitrogen, sulphur, calcium and sodium mentioned in that work is not seen in the present results.

Earlier work on this farm showed that the soil has large numbers of broad-leaved dock seeds that germinate readily when the soil is free of competition during establishment of new pastures (Harrington et al. 2013). Given that the soil parameters measured did not assist with explaining why dock plants were at higher densities in some areas than others, a logical explanation is probably that the species had established whenever the pasture cover has been disturbed sufficiently in the past to allow seeds to germinate and establish successfully. Rothmaler (2009) considered the presence of docks indicated trampling and disturbance of the site.

As an indirect measure of nutrient levels in the soil for each quadrat, nutrient levels within the perennial ryegrass plants were measured. However, another interpretation of the data is that where high densities of the weed were present in the soil, they may have removed certain minerals selectively from the soil to result in lower amounts in surrounding perennial ryegrass. In earlier work conducted at this site, it was found that broad-leaved dock contained much higher quantities of magnesium and manganese than other plant species (Harrington et al. 2006). There was a significant negative correlation in the present work between dock density and both of these minerals, suggesting that the results can be explained by depletion of these minerals from the soil by the dock plants. Likewise, Californian thistle accumulated significantly higher levels of sulphur than perennial ryegrass and white clover, and a negative correlation was found in the current work between the presence of this weed and sulphur levels in the ryegrass.

An added complication is that manganese becomes less available within the soil as pH increases (Sims 1986). For the broadleaved dock quadrats, there was a significant negative correlation (r = -0.33) between manganese levels in perennial ryegrass and soil pH. Given that dock densities were correlated with soil pH, another possible explanation for the correlation between dock density and manganese could be explained simply by the effect of pH on manganese availability. However, the correlation between magnesium and pH was -0.04, so, unlike manganese, the correlation with magnesium cannot be explained by a relationship with pH. Likewise, the correlation between pH and potassium in dock quadrats was only +0.12.

Thus it appears that apart from a weak positive relationship with soil pH, variability in the density of broad-leaved dock and Californian thistle could not be readily explained by the soil parameters that were measured. Their presence can probably be more logically explained by disturbance of the patches in the past that have allowed seedlings to establish. Or perhaps the establishment of these perennial species in the various patches dated back to when the pastures were first sown, at which time perennial weeds can establish readily (Harrington et al. 2013).

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REFERENCES

Anderson WP 1999. Perennial weeds: characteristics and identification of herbaceous species. Iowa State University Press, Ames, Iowa, USA. 228 p.

Boas F 1958. Indicator plants (weeds in arable land). Ackerbau, Hanover, Germany. 20 p.

Bohner A 2001. Physiology and nutritive value of docks. Alpenlandische Expertenforum zum Thema 'Bestandesfuhrung und Unkrautregulierung im Grunland Schwerpunkt Amber', 22-23 March 2001, BAL Gumpenstein, Irdning, Austria. Pp. 39-44.

Harrington KC, Kemp PD, Horne DJ, He XZ 2013. Weed population dynamics for contrasting organic pasture establishment techniques. New Zealand Plant Protection 66: 110-117.

Harrington KC, Osborne MA, Kemp PD 2012. Effect of 10 years of organic dairy farming on weed populations. Proceedings of the 18th Australasian Weeds Conference: 159-162.

Harrington KC, Thatcher A, Kemp PD 2006. Mineral composition and nutritive value of some common pasture weeds. New Zealand Plant Protection 59: 261-265.

Holzner W 1982. Weeds as indicators. In: Holzner W, Numata N ed. Biology and ecology of weeds. Dr W Junk Publishers, The Hague, Netherlands. 461 p.

Hopkins A, Green JO 1979. Effect of soil fertility and drainage on sward changes. In: Charles AH, Haggar RJ ed. Changes in sward composition and productivity. Occasional Symposium No 10, British Grassland Society, Hurley, UK. 253 p.

Pfeiffer EE 1970. Weeds and what they tell. Biodynamic Literature, Wyoming, Rhode Island, USA. 96 p.

Munson RD, Nelson WL 1990. Principles and practices in plant analysis. In: Westerman RL ed. Soil testing and plant analysis, 3rd Edition. Soil Science Society of America, Madison, Wisconsin, USA. 784 p.

Rothmaler W 2009. Exkursionsflora von Deutschland: Gefäßpflanzen (19th ed. Vol. 2). Spektrum Akademischer Verlag, Heidelberg, Germany. 756 p.

Sims JT 1986. Soil pH effects on the distribution and plant availability of manganese, copper and zinc. Soil Science Society of America Journal 50: 367-373.