Impact of Soil Conditions on the Ability to Control *Verticillium* Wilt of Potato in the Lower Columbia Basin

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Introduction

In the past decade, several corporate farms in the lower Columbia Basin in both Washington and Oregon have reported decreased potato yields with each subsequent potato crop, even where metam sodium has been used. Preliminary soil sampling in Washington conducted to help determine the cause of the declining yields revealed high levels of *Verticillium dahliae* in the majority of the fields, particularly in areas with high milliequivalents of calcium. As might be expected, poor plant growth occurred where high calcium levels were found.

Research has shown no economic loss when soil-borne *V. dahliae* levels at planting are below 10 colony forming units (CFU)/gram of dry soil (number of microsclerotia), particularly for susceptible cultivars like Russet Burbank. Generally, after testing hundreds of soils from the Basin over many years, the average level of *V. dahliae* prior to soil fumigation with metam sodium was found to be approximately 20-40 CFU's/gram of dry soil or less. Following fumigation, population levels generally decrease to 0-7 CFU's/gram of dry soil. *Verticillium dahliae* levels in high calcium areas from a farm in Washington have been in the hundreds (<400) of CFUs prior to fumigation and still have substantial soil population levels following fumigation (<200). Post fumigation levels in the high calcium areas substantially exceed the 10 CFU threshold.

High calcium levels in soil are intertwined with many soil characteristics such as pH, soil texture, and calcium carbonate equivalent and soil effervescence. Many soil nutritional components are also affected by high calcium levels in the soil such as phosphorous and metal availability (Zn, Mn, Cu, Mo and Fe). Commonly, terms such as high calcium, high pH and high lime are used interchangeably, which may or may not be true depending on an individual situation.

There have been a number of reports that suggest that high levels of lime favor *Verticillium* infection and/or damage. There are at least three possible reasons as to how lime/calcium levels may influence *Verticillium* populations. One, high calcium/lime levels may have a negative impact on plant growth which may prevent the plant from being able to effectively fight the invasion of the fungus. In this situation the fungus may be able to produce higher levels of microsclerotia in the plant tissue that are then released into the soil as the organic matter breaks down. These microsclerotia can persist in the soil until the next potato crop. Poor plant growth may or may not be directly related to the elevated calcium or *Verticillium* populations, and secondary issues such as water holding capacity or metal availability may also be important. A second possibility of influence is that high levels of lime actually directly encourage development of the disease (invasion of plant tissue, production of microsclerotia, fungus growth in the plant, etc), regardless of the host plant and its health. Lastly, high pH levels may be impacting fumigant efficacy either by deactivating the fumigant and/or influencing the penetration of the fumigant in the soil resulting in more microsclerotia surviving fumigation. Sclerotia in these areas could accumulate over time as more *Verticillium* would escape fumigation, and therefore population levels would increase to the very high numbers that have been recently tabulated.

Fumigant penetration is related to water infiltration. Soil pH can be an indicator of poor infiltration, as can several other soil properties such as bulk density, texture, organic matter content and others. Sodium (a component of metam sodium but not metam potassium) is a major contributor to poor infiltration because of its negative impact on soil structure. Water infiltration impacts may be a large contributor to poor fumigation, particularly in fields where areas of sandy and high calcareous areas co-exist. When applying water carrying metam sodium in sandy soils one might apply a different rate (less water) than to a field that has heavy soil, to get the same level of penetration. Fields that have multiple soil types may make determining the correct amount of water to use very difficult to obtain the best possible fumigation effects. In addition, infiltration issues between soil types may actually cause water carrying fumigant to "run off" and not provide an adequate fumigation.

Nematode populations may also be impacted differentially in these areas due to efficacy of the fumigant. Given the presence of *Pratylenchus penetrans* in some fields in the Columbia Basin and the direct relationship of increase levels of this nematode with increased severity of *Verticillium* infection and subsequent symptoms of early die, following the population of the nematodes is also very important. Furthermore, if calcareous soils decrease the efficacy of fumigants, nematodes, including Columbia root-knot nematode may be more difficult to control.

The specific objectives of this work were: 1) Determine if metam sodium use is as efficacious in controlling/reducing *V. dahliae* microsclerotia and nematodes in areas with high soil calcium versus areas with low soil calcium; 2) Determine if the method of application of metam sodium and the use of other fumigation products impact efficacy to reduce *Verticillium* and nematode levels in high calcium areas; 3) Determine if there is a correlation between soil properties, *V. dahliae* microsclerotia and nematode levels with potato yield; 4) Determine if microsclerotia of *V. dahliae* and nematodes are higher following a potato crop between areas of low and high soil calcium; and 5) Determine if plant nutrient status as determined by petiole analysis (first year) in mid-season or/and whole plant samples (second year) help determine whether *V. dahliae* infection is the primary problem or secondary cause of yield reductions that are occurring where high calcium soils are found.

Methods

This study was conducted over the 2009 and 2010 growing seasons. A total of six potato fields, three fields each year, were used. Selected fields had areas of both high and low calcareous soils. In the high and low calcareous soil areas of each field, 24 by 60 foot plots representing one replicate of each fumigation treatment were randomly organized within a single block. There were six fumigation treatments in 2009 (Table 1a) and eight in 2010 (Table 1b), untreated control included. Therefore in 2009, there were two main plots in each field, one in high calcareous soil the other in low calcareous soil. Within each main plot there were randomized subplots consisting of the different fumigation treatments. Prior to treatment application, ten soil cores were collected from each treatment plot at both the 0-12 and 12-24 inch depths and bulked into one soil sample for each depth. These pre-fumigation soils were collect on October 13, 2008 for the 2009 study and October 20, 2009 for the 2010 study. Soil samples were sieved and mix thoroughly before being assayed for *Verticillium dahliae*, *Fusarium* spp., *Pythium* spp., and pathogenic and free living nematodes levels using standard laboratory practices. Soils were also analyzed for pH, OM, P, K, S, B, Zn, Mn, Cu, Fe, NO_3, NH_4, Ca, Mg, Na as well as effervescence, calcium carbonate equivalent, and texture. Fumigation was performed in the fall of 2008 for the 2009 growing season and the fall of 2009 for the 2010 growing season. Plots were resampled at both depths the following spring both years (February 16, 2009 and March 30, 2010) to determine post-fumigation soil levels of *V. dahliae*, Fusarium spp., Pythium spp., pathogenic and free living nematodes, as well as soil nutrients and characteristics. A third soil sample was collected from each sub-plot at both depths just prior to harvest of each year and assayed for *V. dahliae*, *Fusarium* spp., *Pythium* spp., and pathogenic and free living nematodes.

During the second week of August in 2009 and 2010, five potato vines were destructively sampled from each fumigation sub-plot for quantification of in-plant *V. dahliae* levels. Plant sap was extracted from surface disinfected sections of vines four inches above and below the soil line. Equal amounts of sap from the five vines were bulked, diluted in sterile water, and plated onto *V. dahliae* selective media. Total number of colonies was tabulated and the colony forming units (CFU) per milliliter of vine sap was calculated. In 2010, the causal agent of black dot (*Colletotrichum coccodes*) was quantified in addition to *V. dahliae* using the same technique.

In both years of the study, yield was determined by hand harvesting tubers from two 10-foot long hills located in the center of each treatment plot. Harvest occurred on September 22, 2009 and October 23, 2010. Tubers were sorted and weighed at the OSU Hermiston Agricultural Research and Extension Center sorting facility.

In most instances, data was analyzed three ways: comparing the average of the high and low calcareous plots, regardless of fumigation treatment; comparing the averages of the fumigation treatments regardless of soil calcium levels; and comparing the averages of each fumigation/soil calcium level combination as if each combination was a single treatment. Years were analyzed separately.

Results

Year 1 (Beginning Fall 2008)

<u>Soil borne fungi</u>

Overall, numbers of *Fusarium* and *Pythium* spp. did not differ between high and low calcareous areas prior to fumigation while significantly higher numbers of *Verticillium dahliae* did occur (Table 1a) at the 0-12 inch soil depth. *Fusarium* levels were significantly impacted following some fumigation treatments. No differences among treatments were evident between 13-24 inches for any fungi (Table 2a). None of the fumigation treatments significantly controlled soil borne fungi better than another, regardless of soil calcium levels, at either soil sampling depth. Numbers of *Verticillium dahliae* propagules did not increase to higher levels in the high calcareous areas at season's end compared to low calcareous levels, though the population of this fungus was still numerically higher at that sampling time. Sampling in season of sap from plant stems from each treatment and replication found varying levels of *Verticillium dahliae* infection (Table 3a).

Yield

Total yield was always numerically lower in the high calcareous areas compared to the low calcareous areas (Table 4a), regardless of treatment. None of the fumigation treatments significantly increased yields. Total tuber count was significantly lower in the high calcareous areas.

Nematodes

Before treatment, populations of root-lesion nematodes (*Pratylenchus neglectus*) were significantly higher at both depths in areas with high calcareous soil in all three fields individually (data not shown) as well as overall (Table 5a and 6a). Effect of soil was also significant for both depths on the post fumigation sample date and for the 0-12 in. depth at harvest. Root-lesion nematode densities were not different between plots designated for the different fumigation treatments before treatment. Post fumigation populations of root-lesion nematodes from the top foot of low calcareous soils were 40%, 89%, 95%, 98% and 100% less than nontreated plots in WRMS, SHMS, WRMS + SHMS, Telone C17, and Telone + WRMS treatments, respectively. However, only the last three treatments listed were significantly different (Table 5a). There was a trend for lower populations with treatments in high calcareous soils but this was not significant. Populations in the Telone C17 treatment were significantly higher in high calcareous soil than in low calcareous soil. Root-lesion nematode densities were low in the 12-24 in. depth and there was no effect of treatment (Table 6a). By harvest, populations in the soil had declined to low levels and no effect of treatment was evident.

Before treatment, populations of free-living nematodes were not different between low and high calcareous soils at either depth, and plots designated for the different fumigation treatments were not different (Tables 7a and 8a). Effect of fumigation was significant in both soil types. In areas of low calcareous soil, densities at 0-12 in. were significantly less in the WRMS, Telone C17, and Telone + WRMS treatments. In high calcareous soils, SHMS, WRMS + SHMS, and Telone + WRMS treatments had fewer free-living nematodes than nontreated plots. After treatment, populations in the WRMS + SHMS treatments were lower in high calcareous soil than in low calcareous soil and those in the Telone C17 treatment were higher in high calcareous soil (Table 6a). There was no effect of fumigation in the 12-24 in. depth. At harvest the average number of free-living nematodes in the 12-24 in. depth was significantly higher in the areas with low calcareous soil. No effect of treatment remained in either type of soil.

Nutritional

Pre and post fumigation soil samples were analyzed for a multitude of fertility and soil characteristics. This data is shown in three tables. Table 8 presents a comparison of the three fields. Largely, there is little difference observed between fields. Table 9 compares the high soil calcium areas to the low soil calcium areas across all three fields. There were few significant differences measured, some are unexplainable and need more examination. For example the high calcium areas had 22.4 meq/100g while the low had 8.1 meq/100g, yet these values were not significantly different. These differing levels were the reason why the locations were selected for the study, so the difference is not surprising; however the lack of significance was unexpected.

The lack of a pH response to calcium could be linked to elemental sulfur applications that occurred on the high pH areas of the field. The difference in sodium confirms selection by calcium level.

Table 10 shows treatment effect on soil characteristics. A number of interesting treatment effects were noted. Differences in ammonia (NH_4) levels in the pre plant samples are a good indication of fumigant biological impact. The higher the ammonia value and the lower the nitrate (NO3) amount measured is an indication of the fumigation effect on nitrifying microorganisms. More ammonia likely means more soil borne organisms killed by the fumigation treatment. The high ammonia level in treatment F shows up as a significant difference in cation exchange capacity (CEC) which is not realistic. In addition, there are interesting differences between pre plant and post plant samples by fumigation treatment. Soluble salts (SS) were not different pre-plant yet post-plant sampling indicated levels there are differences between 0.35 mmhos/cm to 0.57 mmhos/cm. A similar situation exists for soil pH. The differences seen in post potato crop sampling compared to pre-potato crop are most likely due to the soil not having been warm enough to create many of these differences during the winter. In other words, the full impact of fumigation was not measured until after the growing season.

Year 2 (Beginning Fall of 2009)

Soil Borne Fungi

Total colony forming units of *Pythium*, *Fusarium*, and *Verticillium dahliae* did not differ significantly between fumigation treatment plots or high and low calcareous areas prior to fumigation at both the 0-12 inch (Table 1b) and 13-24 inch (Table 2b) soil depths. As would be expected, post fumigation fungi counts were lower than pre-fumigation counts for the majority of the treatments at both soil depths. At the 0-12 inch soil depth, the combined metam sodium shanked and water run treatment was the most effective in controlling *Pythium* and *Fusarium* spp. Shanked metam sodium and shanked Telone C-17 were the least effective in controlling *Pythium* and *Fusarium* spp. at that depth. No one treatment was more effective than another in controlling *Verticillium dahliae* at either soil depth. When fumigated high and low calcareous soils were compared, post fumigation *V. dahliae* counts were significantly lower in the low calcareous soils at both soil depths.

In Plant *V. dahliae* and *Colletotrichum coccodes*

In season sampling of plant sap showed that the *V. dahliae* CFU/mL plant sap from fumigated plots with high calcareous soils were always greater than the low calcareous plots of the corresponding treatments. This difference was significant for metam sodium water run as well as one of the shanked metam sodium treatments (Table 3b). When comparing just high calcareous soil to low calcareous soil, regardless of fumigant, the plant sap from high calcareous areas had significantly higher levels of *V. dahliae* than the low calcareous sap.

Nematodes

Nematode population densities were considerably lower in the in the fields chosen for the study in 2009-10. There were no differences in levels of root-lesion nematodes between low and high calcareous soils before fumigation at either depth. However, after fumigation, population densities were higher in high calcareous soils at both depths when averaged over all treatments (Table 5b, 6b) No fumigation treatment had any effect on root-lesion densities and there was no effect of soil Ca on the performance of any treatment. By harvest, populations in the soil had declined to low levels and no effect of treatment or soil was evident.

After fumigation, free-living nematodes in the top foot of soil were more abundant in the high calcareous plots when averaged over all treatments (Table 7b, 8b). In low calcareous soils, post treatment population densities of free-living nematodes at 0-12 in. were significantly less in the WRMS and SHMS treatments than in the untreated plots. At 12-24 in. the WRMS and Telone plus MS treatments had fewer (P = 0.0745) free-living nematodes than the control plots. No treatments were different from the control in high calcareous soil sites. No effect of treatment or soil condition was apparent at either depth by harvest

Nutritional: Main effects (Soil pH/Ca)

Some effects of soil pH and calcium were significantly different from each other, while others were not. Soil pH had no effect on the phosphorous availability in the soil including both the bicarbonate extractable P (P) and the water extractable P (WSP) (Table 13). This is surprising because high soil pH is commonly credited as being the main cause for low soil test P. This expected low available P in the high calcium and high pH environments is often credited with early death and poor performance of potato in areas where this high pH situation exists. The difference in calcium between the low and high pH areas is not surprising as this is why these locations were chosen. The high soluble salts (SS) and extractable sulfur (S) differences were expected in the high pH areas as compared to the low pH areas as elemental sulfur was applied to all treatments in the high pH areas prior to fumigation in an attempt to combat the high calcium and elevated pH. The surprising thing is how fast the sulfur was generated since fumigation and temperature should have interfered with the soil's ability to convert elemental sulfur to sulfate (extractable S). Part of the explanation for the large difference in extractable sulfur might be a remnant of past applications. Elemental S does not react very fast in soils, so previous applications, not the application the preceding fall may have been responsible for the elevated sulfur levels observed in the high pH soils. The higher soluble salts (SS) is a result of the higher sulfur in the soil. Soluble salts measures anything that is easily extracted from the soil.

The lack of difference by soil pH in metals such as zinc, copper, manganese and iron is a little surprising. This may due to the effectiveness of the acidification treatments, as post fumigation soil pH for the acid soil fields averaged 5.9 and 6.5 for the high calcium fields. Some of the high calcium areas actually had a soil pH below 5 (Table 14), particularly after sulfuric acid application, where treatment 8 dropped to 4.4 in field three as seen in the above table. Soil pH of the three fields for the low pH areas were 5.8, 5.8 and 5.9 averaged across treatments. Soil pH for the three fields for the high pH areas were 7.4, 7,4 and 4.6 averaged across the 8 treatments. The low pH of field three for the supposed high pH main effect may suggest why some of the metals and such are not significantly different, though trends indicate a pH effect. Low calcium levels (less than 5 meq/100g) in field three also suggest that this location may not have been properly chosen. The lower pH and elevated sulfur in the high pH area does suggest that the treatments were properly applied.

Figures 1 and 2 show the effect pH has on some of the measured soil parameters. This is another way of looking at the effect of soil pH on metal availability. Water soluble P (WSP) and zinc were not affected by soil pH in Figure 1. Copper on the other hand decreases with increasing pH. Figure 2 shows how manganese and iron are influenced by soil pH. When pH decreases, solubility in the soil increases by almost 100 fold. Extractable manganese goes from less than 5 ppm when soil pH is above 7 to over 100 ppm when soil pH drops below 5.0.

Nutritional: Treatment Effects

Treatment 8 was 40 gallons of metam sodium plus the addition of sulfuric acid. This treatment should have resulted in differences between metal content. Metals such as iron, manganese and zinc should have been higher in this treatment compared to the other treatments. This, however, was not observed. Sulfuric acid reacts in soils much more quickly than elemental sulfur. The untreated treatment (1) and the treatment with sulfuric acid (8) were different from each other with the sulfuric acid treatment being higher. Soil test levels of phosphorous for both water extractable and bicarbonate was the highest for treatment 8 compared to all other treatments. This suggests the soil acidification with sulfuric acid is having an effect.

Fumigation had a significant effect on soil test properties as shown in Table 15. However, there are no consistent trends between the different analytes tested. The previous year's data showed the more rigorous the fumigation the more ammonia that was present. Treatment 7, metam plus Telone II, was higher in ammonia than the other treatments. This was not observed in this year's sampling.

Soil pH by treatment is shown in Table 16. Metam sodium water ran (2) had the lowest soil pH following fumigation. This treatment had a lower soil pH than the sulfuric acid treatment (8). Treatment 2 and 8 had the highest ammonia and the lowest calcium levels than any of the other treatments.

Yield

There were no significant yield differences between the high and low calcareous plots of each treatment (Table 4b). When both high and low calcareous plots of each treatment were combined, metam sodium water run; metam sodium water run and shanked; Telone II with metam sodium; and the metam sodium with sulfuric acid had significantly great yields of the 4-8 oz tuber size than the control. Metam sodium water run at 40 gpa had a significantly higher total yield than the control when high and low calcareous yields were combined.

Conclusions

Levels of *V. dahliae* where nearly always numerically higher in the high calcareous areas following fumigation compared to low calcareous areas, regardless of soil depth. There were no clear differences in reduction of *V. dahliae* occurring between the different fumigation treatments. Data indicate that regardless of fumigation material, reductions in *V. dahliae* were greater in the low calcareous areas compared to high calcareous locations. While beginning levels of *V. dahliae* were usually higher in the high calcareous areas when the potato crop was planted, the changes in levels of *V. dahliae* between planting and harvest were numerically greater following the potato crop in high calcareous areas compared to low calcareous locations. Levels of *V. dahliae* in year two were always numerically higher in the potato stem tissue from high calcium areas.

There was a trend for root-lesion-nematodes to be more abundant in high calcareous soils from the top foot but not from the second foot. These results were significant on all three sample dates in year one and one sample date in year two with the other two dates numerically higher. The reason for this relationship is still not understood.

There was little indication that high calcareous soils had any influence on performance of fumigants with regard to nematode control. In year one, three of the five treatments significantly reduced population densities of root-lesion nematodes in low calcareous sites and no treatments were significantly different from untreated plots in the high calcareous sites which suggests a negative effect of soil Ca on fumigant performance. However, the lack of significance is due more to variability than to a difference in effectiveness of the treatments. When percent reduction of the populations in the two sites is compared for each individual treatment the results are similar between low and high calcareous soils. Therefore, the few differences in treatments noted between the different soils in year one are more likely the result of happenstance than to any consistent effect of high calcareous soils on fumigant performance. Similarly, there was no effect of any treatment on root-lesion nematodes in year two in either type of soil so no effect of soil condition on fumigant performance could be established.

Only year one (2009) had high enough root-lesion nematode densities to evaluate treatments. There were no significant differences between treatments in the high calcareous site but looking at percent reduction, population levels from the top foot in the high calcareous site were reduced more by WR MS than by shanked MS. However best reduction with metam sodium was in the Shanked + WR MS treatment which was similar to the Telone + WRMS treatment. Population densities in the second foot were too low to meaningfully evaluate treatments.

Further analysis is needed on how soil properties in the high calcareous and low calcareous soils impact fumigant efficacy with regard to the influence of soil nutrition, soil fungi and nematode levels on yield. The dynamics of this interaction is likely to be highly variable.

Table 1a. Year one (2009) effects of soil fumigation on soil borne fungi between 0-12 inches.

Treatment	Depth (in.)[2]	Calcium Level[3]	*Pythium* spp. (CFU/g dry soil)[1] Pre	*Pythium* spp. Post	*Pythium* spp. Harvest	*Fusarium* spp. (CFU/g dry soil)[1] Pre	*Fusarium* spp. Post	*Fusarium* spp. Harvest	*Verticillium dahliae* (CFU/g dry soil)[1] Pre	*Verticillium dahliae* Post	*Verticillium dahliae* Harvest
Control	0-12	High	9.0 [4]	24.7 a	73.3 a	2979 a	5305	3232 a	40.7 a	43.3 a	27.3 a
Control	0-12	Low	8.7 a	14.7 a	3.7 a	5434 a	2883	3083 a	2.7 a	9.3 a	4.0 a
MS WR @ 40gpa[5]	0-12	High	11.0 a	11.3 a	15.0 a	3870 a	4703	3256 a	22.7 a	30.7 a	13.3 a
MS WR @ 40gpa	0-12	Low	23.3 a	25.7 a	63.7 a	5336 a	2094	3303 a	9.3 a	14.7 a	4.7 a
MS Shanked @ 40gpa	0-12	High	23.7 a	20.7 a	30.7 a	2998 a	3230	2763 a	38.7 a	42.7 a	34.7 a
MS Shanked @ 40gpa	0-12	Low	16.3 a	31.3 a	11.0 a	4340 a	2169	2379 a	9.3 a	15.3 a	6.7 a
MS Shanked (40gpa) and WR (40gpa)	0-12	High	24.0 a	22.3 a	39.3 a	3728 a	1457	2681 a	35.3 a	57.3 a	6.0 a
MS Shanked (40gpa) and WR (40gpa)	0-12	Low	11.0 a	22.0 a	53.7 a	4542 a	5261	3441 a	8.7 a	5.3 a	4.7 a
Telone C-17 (20gpa)	0-12	High	34.0 a	13.0 a	7.7 a	4876 a	3108	2344 a	20.0 a	35.3 a	1.3 a
Telone C-17 (20gpa)	0-12	Low	7.0 a	21.7 a	89.7 a	4958 a	3332	3301 a	5.3 a	8.7 a	0.7 a
Telone @ 15g/A + MS WR @ 40g/A	0-12	High	NA[7]	11.7 a	50.0 a	NA[7]	2811	2913 a	NA[7]	20.0 a	6.0 a
Telone @ 15g/A + MS WR @ 40g/A	0-12	Low	NA[7]	0.0 a	62.3 a	NA[7]	1505	2344 a	NA[7]	12.7 a	0.7 a
Control	0-12	Both[6]	8.8 a	19.7 a	38.5 a	4207 a	3381 a	3157 a	21.7 a	26.3 a	15.7 a
MS WR @ 40gpa	0-12	Both	17.2 a	18.5 a	39.3 a	4603 a	4072 a	3280 a	16.0 a	22.7 a	9.0 a
MS Shanked @ 40gpa	0-12	Both	20.0 a	26.0 a	20.8 a	3669 a	3906 a	2571 a	24.0 a	29.0 a	20.7 a
MS Shanked (40gpa) and WR (40gpa)	0-12	Both	17.5 a	22.2 a	46.5 a	4135 a	2713 ab	3061 a	22.0 a	31.3 a	5.3 a
Telone C-17 (20gpa)	0-12	Both	20.5 a	17.3 a	48.7 a	4917 a	3021 ab	2822 a	12.7 a	22.0 a	1.0 a
Telone @ 15g/A + MS WR @ 40g/A	0-12	Both	NA[7]	5.8 a	56.2 a	NA[7]	1837 b	2629 a	NA[7]	16.3 a	3.3 a
Overall all Treatments[8]	0-12	High	20.3 a	17.3 a	36.0 a	3690 a	3397 a	2865 a	31.5 a	38.2 a	14.8 a
	0-12	Low	13.3 a	19.2 a	47.3 a	4922 a	2912 a	2975 a	7.1 b	11.0 a	3.6 a

Table 1b. Year two (2010) effects of soil fumigation on soil borne fungi between 0-12 inches.

Treatment	Depth (in.)[2]	Calcium Level[3]	*Pythium* spp. (CFU/g dry soil)[1]			*Fusarium* spp. (CFU/g dry soil)[1]			*Verticillium dahliae* (CFU/g dry soil)[1]		
			Pre	Post	Harvest	Pre	Post	Harvest	Pre	Post	Harvest
Untreated Control	0-12	High[9]	121	130 a	61	4300	2405 cde	1350 cde	32 ab	22 abcd	43 ab
Untreated Control	0-12	Low	110	39 bc	144	4060	1868 cdef	1655 bcde	19 ab	6 cd	26 ab
MS WR @ 40 gpa[5]	0-12	High	88	18 c	61	2654	2737 bcd	1363 cde	19 ab	36 a	56 a
MS WR @ 40 gpa	0-12	Low	118	6 c	165	3851	1704 def	1256 cde	18 ab	8 bcd	13 b
MS Shanked (40gpa) and WR (40gpa)	0-12	High	139	6 c	34	3285	1410 ef	2265 abcd	18 ab	25 abcd	48 ab
MS Shanked (40gpa) and WR (40gpa)	0-12	Low	115	3 c	101	5645	944 f	1297 cde	7.33 b	5 cd	13 b
MS Shanked @ 40 gpa	0-12	High	170	137 a	128	4183	3036 bc	2249 abcd	14 ab	19 abcd	64 a
MS Shanked @ 40 gpa	0-12	Low	124	44 bc	165	4893	3734 ab	2511 ab	6 b	5 cd	33 ab
Telone C-17 Shank @ 22 gpa	0-12	High	148	149 a	94	3852	3043 bc	2129 abcd	25 ab	30 abc	44 ab
Telone C-17 Shank @ 22 gpa	0-12	Low	171	94 ab	181	6839	4405 a	2871 a	24 ab	12 abcd	12 b
MS Shanked @ 40 gpa	0-12	High	137	118 a	92	3397	2879 bcd	2330 abc	30 ab	16 abcd	51 ab
MS Shanked @ 40 gpa	0-12	Low	96	44 bc	150	4932	1859 cdef	1503 bcde	21 ab	2 d	27 ab
Telone II @20 gpa+MS @ 40 gpa	0-12	High	164	19 c	71	4686	2292 cde	1597 bcde	30 ab	32 ab	55 a
Telone II @20 gpa+MS @ 40 gpa	0-12	Low	38	7 c	97	5957	1778 def	975 e	23 ab	14 abcd	29 ab
MS 40 @ gpa+ Sulfuric Acid	0-12	High	132	30 c	59	4141	1744 def	2168 abcd	46 ab	24 abcd	59 a
MS 40 @ gpa+ Sulfuric Acid	0-12	Low	47	13 c	68	4034	1695 def	1141 de	37 ab	8 bcd	35 ab
Untreated Control	0-12	Both[6]	114	75 ab	111	4156	2083 b	1533 c	24 ab	12	33
MS WR @ 40 gpa	0-12	Both	106	11 c	123	3372	2117 b	1299 c	18 b	19	30
MS Shanked (40gpa) and WR (40gpa)	0-12	Both	125	4 c	74	4701	1130 c	1684 bc	12 b	13	27
MS Shanked @ 40 gpa	0-12	Both	142	81 a	150	4868	3455 a	2406 ab	9 b	10	45
Telone C-17 Shank @ 22 gpa	0-12	Both	162	116 a	146	5644	3860 a	2574 a	24 ab	19	25
MS Shanked @ 40 gpa	0-12	Both	112	73 ab	127	4318	2267 b	1834 abc	25 ab	8	37
Telone II @20 gpa+MS @ 40 gpa	0-12	Both	89	12 c	86	5448	1983 bc	1224 c	26 ab	21	40
MS 40 @ gpa+ Sulfuric Acid	0-12	Both	81	20 bc	64	4077	1715 bc	1552 c	40 a	14	44
Overall all Treatments[8]	0-12	High	137	68	76 a	3835 a	2448	2014	26	26 a	54 a
	0-12	Low	101	30	132 b	5164 b	2302	1650	19	8 b	23 b

Table 2a. Year one (2009) effects of soil fumigation on soil borne fungi between 12-24 inches.

			Pythium spp. (CFU/g dry soil)[1]			*Fusarium* spp. (CFU/g dry soil)[1]			*Verticillium dahlia* (CFU/g dry soil)[1]		
Treatment	Depth (in)[2]	Calcium Level[3]	Pre	Post	Harvest	Pre	Post	Harvest	Pre	Post	Harvest
Control	12-24	High	9 a[4]	12 a	48 a	3921 a	2396	1386 a	15 a	13 a	17a
Control	12-24	Low	17 a	11 a	53 a	4231 a	710	1910 a	18 a	6 a	5 a
MS WR @ 40gpa[5]	12-24	High	17 a	9 a	21 a	2400 a	1108	1397.a	15 a	17 a	4 a
MS WR @ 40gpa	12-24	Low	12 a	30 a	28 a	3703 a	2109	1547 a	13 a	10 a	6 a
MS Shanked @ 40gpa	12-24	High	18 a	15 a	31 a	3769 a	2524	1183 a	14 a	26 a	5 a
MS Shanked @ 40gpa	12-24	Low	28 a	9 a	22 a	4375 a	963	1429 a	15 a	7 a	4 a
MS Shanked (40gpa) and WR (40gpa)	12-24	High	15 a	4 a	34 a	4428 a	657	949 a	9 a	8 a	5 a
MS Shanked (40gpa) and WR (40gpa)	12-24	Low	9 a	13 a	56 a	3887 a	1186	1852 a	17 a	5 a	16 a
Telone C-17 (20gpa)	12-24	High	8 a	6 a	0 a	4071 a	1141	1188 a	11 a	19 a	3 a
Telone C-17 (20gpa)	12-24	Low	18 a	4 a	56 a	2717 a	806	1383 a	17 a	5 a	3 a
Telone @ 15g/A + MS WR @ 40g/A	12-24	High	NA[7]	2 a	30 a	NA[7]	405	2563 a	NA[7]	10 a	10 a
Telone @ 15g/A + MS WR @ 40g/A	12-24	Low	NA[7]	4 a	18 a	NA[7]	510	1354 a	NA[7]	9 a	7 a
Control	12-24	Both[6]	18 a	11.3 a	51 a	4148 a	1553 a	1648 a	15 a	9 a	11 a
MS WR @ 40gpa	12-24	Both	16 a	19.8 a	24 a	4329 a	1608 a	1472 a	14 a	14 a	5 a
MS Shanked @ 40gpa	12-24	Both	13 a	12.3 a	27 a	3143 a	1743 a	1306 a	16 a	17 a	5 a
MS Shanked (40gpa) and WR (40gpa)	12-24	Both	10 a	8.3 a	45 a	3887 a	921 ab	1400 a	12 a	7 a	11 a
Telone C-17 (20gpa)	12-24	Both	18 a	4.8 a	28 a	3243 a	973 ab	1286 a	15 a	12 a	3 a
Telone @ 15g/A + MS WR @ 40g/A	12-24	Both	NA[7]	2.8 a	24 a	NA[7]	457 b	1958 a	NA[7]	10 a	8 a
Overall all Treatments[8]	12-24	High	15 a	8.0 a	27 a	3605 a	1371 a	1444 a	15 a	16 a	8 a
	12-24	Low	15 a	12 a	39 a	3895 a	1047 a	1579 a	14 a	7 a	7 a

Table 2b. Year two effects (2010) of soil fumigation on soil borne fungi between 12-24 inches.

Treatment	Depth (in.)[1]	Calcium Level[3]	*Pythium* spp. (CFU/g dry soil)[1]			*Fusarium* spp. (CFU/g dry soil)[1]			*Verticillium dahliae* (CFU/g dry soil)[1]		
			Pre	Post	Harvest	Pre	Post	Harvest	Pre	Post	Harvest
Untreated Control	12-24	High[9]	91 a	12	58	1024	1532 abc	973 a	6	20	35
Untreated Control	12-24	Low	13 cd	37	40	886	1387 abcd	299 e	20	5	53
MS WR @ 40 gpa[5]	12-24	High	11 cd	17	92	2572	1232 abcd	832 abcd	31	19	57
MS WR @ 40 gpa	12-24	Low	3 d	30	20	1391	820 bcd	298 e	14	7	20
MS Shanked (40gpa) and WR (40gpa)	12-24	High	6 cd	43	11	660	956 bcd	839 abcd	13	13	173
MS Shanked (40gpa) and WR (40gpa)	12-24	Low	0 d	51	31	1904	726 cd	444 bcde	1	11	17
MS Shanked @ 40 gpa	12-24	High	50 b	34	50	2592	943 bcd	964 ab	6	11	28
MS Shanked @ 40 gpa	12-24	Low	11 cd	32	24	1207	1223 abcd	356 de	9	7	29
Telone C-17 Shank @ 22 gpa	12-24	High	22 cd	37	40	1771	1105 bcd	652 abcde	3	12	59
Telone C-17 Shank @ 22 gpa	12-24	Low	9 cd	41	890	6892	1148 bcd	411 cde	9	0	23
MS Shanked @ 40 gpa	12-24	High	86 a	40	42	1062	2076 a	899 abc	15	14	56
MS Shanked @ 40 gpa	12-24	Low	31 bc	28	34	1960	1700 ab	449 abcde	10	5	33
Telone II @20 gpa+MS @ 40 gpa	12-24	High	6 cd	9	42	1063	780 bcd	566 abcde	24	7	57
Telone II @20 gpa+MS @ 40 gpa	12-24	Low	2 d	26	9	1264	456 d	354 de	10	1	39
MS 40 @ gpa+ Sulfuric Acid	12-24	High	14 cd	14	64	1196	659 cd	902 abc	19	15	72
MS 40 @ gpa+ Sulfuric Acid	12-24	Low	0 a	25	9	1713	927 bcd	483 abcde	15	5	25
Untreated Control	12-24	Both[6]	44 ab	27	47	941	1445 ab	569	14	11	46
MS WR @ 40 gpa	12-24	Both	6 c	25	49	1863	985 bc	512	21	12	35
MS Shanked (40gpa) and WR (40gpa)	12-24	Both	2 c	48	23	1407	818 c	602	6	12	80
MS Shanked @ 40 gpa	12-24	Both	26 abc	33	34	1761	1111 bc	599	8	8	28
Telone C-17 Shank @ 22 gpa	12-24	Both	14 bc	39	550	4843	1131 bc	507	6	5	37
MS Shanked @ 40 gpa	12-24	Both	53 a	33	37	1601	1850 a	629	12	8	42
Telone II @20 gpa+MS @ 40 gpa	12-24	Both	3 c	19	22	1184	586 c	439	16	4	46
MS 40 @ gpa+ Sulfuric Acid	12-24	Both	5 c	20	31	1506	820 c	650	17	9	44
Over all Treatments[8]	12-24	High	27	28	49	1559	1107	807 a	16 a	13 a	72 a
	12-24	Low	8	34	145	2333	1000	399 b	10 b	5 b	27 b

[1]Soil borne populations of each of these fungi were determined prior to fumigation (Pre), post fumigation (Post) and at harvest (Harvest).

[2]Depth of where soil was collected.

[3]Soils were collected from two distinct areas in each of three fields. Each plot contained all fumigation treatments; one plot was in a high calcareous area, the other from a low calcareous area.

[4] Numbers in the same column followed by a different letter are significantly different with in each of the three sub-tables ($P<0.05$). Numbers not followed by a letter or followed by the same letter are not significantly different

[5]MS=Metam Sodium; WR=Water run

[6]Both refers to the inclusion of both the low and high calcareous data for that fumigation treatment.

[7]Treatment not included in the original list but added later so initial samples were not taken.

[8] The values in this sub-table represent the average of all data from all fumigation treatments, excluding control treatments, and are separated by the high and low calcareous areas.

[9] Year two “High” averages were calculated from data collected from only two of the three selected fields. The third field was removed due to improper treatment applications.

Table 3a. Year one (2009) levels of *Verticillium dahliae* in plant sap from potato plants collected during the season[1].

Treatment	Calcium Level	*Verticillium dahliae* (CFU/ml sap)
Control	High	15190 a[2]
Control	Low	15514 a
MS Shanked 40 gpa	High	11613 a
MS Shanked 40 gpa	Low	12616 a
MS Shanked 40 gpa and WR 40 gpa	High	6132 a
MS Shanked 40 gpa and WR 40 gpa	Low	11734 a
MS WR 40 gpa	High	13386 a
MS WR 40 gpa	Low	8775 a
Telone 15 gpa + MS WR 40 gpa	High	6951 a
Telone 15 gpa + MS WR 40 gpa	Low	2787 a
Telone C-17 20 gpa	High	7105 a
Telone C-17 20 gpa	Low	8715 a
Control	Both[3]	15352 a
MS WR @ 40gpa	Both	11081 a
MS Shanked @ 40gpa	Both	12114 a
MS Shanked and WR @ 40gpa	Both	8933 a
Telone C-17	Both	7910 a
Telone @ 15gpa + MS WR @ 40gpa	Both	4869 a
Over all Treatments[4]	High	10063 a
	Low	10023 a

[1]Sap was collected from plants by squeezing stems and then plating the material on selective media. The number of propagules of *Verticillium dahliae* could then be counted.

[2]Numbers in the same column followed by a different letter are significantly different within each of the three sub-tables (P<0.05). Numbers not followed by a letter or followed by the same letter are not significantly different.

[3]Both refers to the inclusion of both the low and high calcareous data for that fumigation treatment.

[4]The values in this sub-table represent the average of all data from all fumigation treatments and are separated by the high and low calcareous areas.

Table 3b. Year two levels (2010) of *Verticillium dahliae* and *Colletotrichum coccodes* in plant sap from potato plants collected during the season[1].

Treatment	Calcium Level	*Verticillium dahliae* (CFU/ml plant sap)	*Colletotrichum coccodes* (CFU/ml plant sap)
Untreated Control	High[5]	2610 ab[2]	440 bc
Untreated Control	Low	857 bcde	17 c
MS WR @ 40 gpa	High	2475 abcd	985 ab
MS WR @ 40 gpa	Low	37 e	20 c
MS Shanked (40gpa) and WR (40gpa)	High	1205 bcde	1450 a
MS Shanked (40gpa) and WR (40gpa)	Low	180 cde	57 c
MS Shanked @ 40 gpa	High	1990 abcde	640 bc
MS Shanked @ 40 gpa	Low	103 de	167 bc
Telone C-17 Shank @ 22 gpa	High	1980 abcde	160 bc
Telone C-17 Shank @ 22 gpa	Low	260 bcde	80 c
MS Shanked @ 40 gpa	High	3785 a	385 bc
MS Shanked @ 40 gpa	Low	870 bcde	517 bc
Telone II @20 gpa+MS @ 40 gpa	High	260 bcde	155 bc
Telone II @20 gpa+MS @ 40 gpa	Low	67 e	57 c
MS 40 @ gpa+ Sulfuric Acid	High	2525 abc	185 bc
MS 40 @ gpa+ Sulfuric Acid	Low	620 bcde	210 bc

Untreated Control	Both[3]	1558	186
MS WR @ 40 gpa	Both	1012	406
MS Shanked (40gpa) and WR (40gpa)	Both	590	614
MS Shanked @ 40 gpa	Both	858	356
Telone C-17 Shank @ 22 gpa	Both	948	112
MS Shanked @ 40 gpa	Both	2036	464
Telone II @20 gpa+MS @ 40 gpa	Both	144	96
MS 40 @ gpa+ Sulfuric Acid	Both	1382	200

Over all Treatments[4]	Low	374 a	140 a
	High	2104 b	550 b

[1]Sap was collected from plants by squeezing stems and then plating the material on selective media.
The number of propagules of *Verticillium dahliae* could then be counted.

[2]Numbers in the same column followed by a different letter are significantly different within each of the three sub-tables (P<0.05). Numbers not followed by a letter or followed by the same letter are not significantly different.

[3]Both refers to the inclusion of both the low and high calcareous data for that fumigation treatment.

[4]The values in this sub-table represent the average of all data from all fumigation treatments and are separated by the high and low calcareous areas.

[5] Year two "High" averages were calculated from data collected from only two of the three selected fields. The third field was removed due to improper treatment applications.

Table 4a. Year one effects (2009) of fumigation treatments on yield and tuber count in high and low calcareous areas.

		Yield (lbs)[1]						
Treatment	Calcium Level[2]	Under 4 oz	Cull's/2's	4 to 8 oz	8 to 12 oz	Over 12 oz	Total Yield	Tuber Count
Control	High	9.0 a[3]	4.1 c	28.2 a	21.6 a	11.8 a	74.7 a	174.3 a
Control	Low	13.0 a	5.0 bc	39.6 a	22.6 a	14.7 a	94.9 a	263.7 a
MS WR @ 40gpa[4]	High	6.6 a	4.6 bc	22.8 a	13.5 a	14.5 a	61.9 a	175.3 a
MS WR @ 40gpa	Low	11.2 a	13.2 ab	38.8 a	21.6 a	13.6 a	98.3 a	255.7 a
MS Shanked @ 40gpa	High	11.4 a	6.6 bc	26.3 a	16.5 a	14.3 a	75.1 a	196.0 a
MS Shanked @ 40gpa	Low	11.6 a	8.4 bc	36.6 a	22.4 a	11.1 a	90.1 a	295.7 a
MS Shanked (40gpa) and WR (40gpa)	High	7.5 a	7.1 bc	18.2 a	15.4 a	23.3 a	71.4 a	179.3 a
MS Shanked (40gpa) and WR (40gpa)	Low	12.6 a	3.4 c	39.4 a	25.1 a	15.6 a	96.0 a	242.7 a
Telone C-17 (20gpa)	High	8.7 a	5.5 bc	25.9 a	19.8 a	14.9 a	74.9 a	224.0 a
Telone C-17 (20gpa)	Low	14.3 a	7.7 bc	36.5 a	27.1 a	11.6 a	97.2 a	249.7 a
Telone @ 15g/A + MS WR @ 40g/A	High	9.1 a	19.7 a	28.2 a	14.3 a	15.6 a	86.9 a	198.3 a
Telone @ 15g/A + MS WR @ 40g/A	Low	15.8 a	3.4 c	48.3 a	21.4 a	9.8 a	98.6 a	292.7 a
Control	Both[5]	11.0 a	4.5 a	33.9 a	22.1 a	13.2 a	84.8 a	219.0 a
MS WR @ 40gpa	Both	8.9 a	8.9 a	30.8 a	17.5 a	14.1 a	80.1 a	215.5 a
MS Shanked @ 40gpa	Both	11.5 a	7.5 a	31.4 a	19.5 a	12.7 a	82.6 a	245.8 a
MS Shanked (40gpa) and WR (40gpa)	Both	10.0 a	5.2 a	28.8 a	20.2 a	19.4 a	83.7 a	211.0 a
Telone C-17 (20gpa)	Both	11.5 a	6.6 a	31.2 a	23.5 a	13.2 a	86.1 a	236.8 a
Telone @ 15g/A + MS WR @ 40g/A	Both	12.4 a	11.6 a	38.2 a	17.9 a	12.7 a	92.8 a	245.5 a
Overall all Treatments	High[6]	8.7 a	7.9 a	24.9 a	16.8 a	15.7 a	74.2 a	191.2 a
	Low	13.1 a	6.9 a	39.9 a	23.4 a	12.7 a	95.9 a	266.7 b

[1]Average yield in pounds from the three replicated plots of each fumigation treatment. Replications were fields.
[2]Soils were collected from two distinct areas in each of three fields. Each plot contained all fumigation treatments; one plot was in a high calcareous area, the other from a low calcareous area.
[3]Numbers followed by t he same letter are not significantly different with in each of the three sub-tables ($P<0.05$).
[4]MS= metam sodium, WR=water run.
[5]Both refers to the inclusion of both the low and high calcareous data for that fumigation treatment.
[6]These values in this sub-table represent the average of all data from all fumigation treatments and are separated by the high and low calcareous areas.

Table 4b. Year two (2010) effects of fumigation treatments on yield and tuber count in high and low calcareous areas.

Treatment	Calcium Level[2]	Yield (lbs)[1] Under 4 oz	Culls/2's	4 to 8 oz	8 to 12 oz	Over 12 oz	Total Yield
Untreated Control	High	12 a	1.3 a	31 a	23 a	15 a	83 ab
Untreated Control	Low	13 a	1.6 a	33 a	22 a	17 a	86 ab
MS WR @ 40 gpa[4]	High	14 a	2.9 a	40 a	29 a	16 a	103 a
MS WR @ 40 gpa	Low	15 a	1.8 a	42 a	28 a	16 a	103 a
MS Shanked (40gpa) and WR (40gpa)	High	13 a	0.9 a	38 a	31 a	11 a	94 ab
MS Shanked (40gpa) and WR (40gpa)	Low	16 a	0.6 a	44 a	25 a	10 a	96 ab
MS Shanked @ 40 gpa	High	12 a	1.4 a	32 a	19 a	8 a	73 b
MS Shanked @ 40 gpa	Low	13 a	3.0 a	32 a	21 a	20 a	89 ab
Telone C-17 Shank @ 22 gpa	High	15 a	3.4 a	40 a	24 a	18 a	100 a
Telone C-17 Shank @ 22 gpa	Low	14 a	0.8 a	37 a	30 a	12 a	93 ab
MS Shanked @ 40 gpa	High	14 a	1.3 a	41 a	23 a	7 a	87 ab
MS Shanked @ 40 gpa	Low	14 a	1.8 a	35 a	24 a	17 a	91 ab
Telone II @20 gpa+MS @ 40 gpa	High	18 a	5.0 a	42 a	28 a	10 a	103 a
Telone II @20 gpa+MS @ 40 gpa	Low	13 a	1.0 a	43 a	22 a	10 a	88 ab
MS 40 @ gpa+ Sulfuric Acid	High	15 a	3.6 a	41 a	27 a	10 a	97 ab
MS 40 @ gpa+ Sulfuric Acid	Low	14 a	2.2 a	40 a	26 a	13 a	94ab
Untreated Control	Both[5]	12.5 a	1.5 a	31.7 b	22.4 ab	16.1 a	84.1 b
MS WR @ 40 gpa	Both	14.6 a	2.4 a	41.2 a	28.9 a	15.9 a	103.0 a
MS Shanked (40gpa) and WR (40gpa)	Both	14.6 a	0.7 a	41.0 a	27.7 a	10.8 a	94.8 ab
MS Shanked @ 40 gpa	Both	12.5 a	2.2 a	32.1 b	19.9 b	14.3 a	81.0 b
Telone C-17 Shank @ 22 gpa	Both	14.4 a	2.1 a	38.7 ab	26.8 ab	14.7 a	96.7 ab
MS Shanked @ 40 gpa	Both	14.1 a	1.6 a	38.2 ab	23.5 ab	11.8 a	89.2 ab
Telone II @20 gpa+MS @ 40 gpa	Both	15.4 a	3.0 a	42.4 a	25.2 ab	9.9 a	95.9 ab
MS 40 @ gpa+ Sulfuric Acid	Both	14.3 a	2.9 a	40.6 a	26.5 ab	11.2 a	95.4 ab
Over all Treatments[6]	High	14.6 a	2.7 a	39.3 a	26.0 a	11.3 a	93.8 a
	Low	14.0 a	1.6 a	39.0 a	25.0 a	14.0 a	93.6 a

[1] Average yield in pounds from the three replicated plots of each fumigation treatment. Replications were fields.
[2] Soils were collected from two distinct areas in each of three fields. Each plot contained all fumigation treatments; one plot was in a high calcareous area, the other from a low calcareous area.
[3] Numbers followed by t he same letter are not significantly different with in each of the three sub-tables ($P<0.05$).
[4] MS= metam sodium, WR=water run.
[5] Both refers to the inclusion of both the low and high calcareous data for that fumigation treatment.
[6] These values in this sub-table represent the average of all data from all fumigation treatments and are separated by the high and low calcareous areas.

Table 5a. Year one (2009) populations of root-lesion nematodes (nematodes/250 g dry soil from 0-12 in.) in different fumigation treatments within low and high calcareous areas of potato fields.

Treatment	Prefumigation[1]	Post Fumigation[2]	Harvest[3]
		Low Calcareous Soils	
Nontreated	86	107 a[4]	11
Water-Run MS 40 gpa	108	64 ab	2
Shanked MS 40 gpa	63	12 abc	1
SH +WR MS 80 gpa	70	5 bc	4
Telone C-17	66	2 c	0
Tel 15 gpa + WRMS 30 gpa	Not Sampled	0 c	1
Pr > F	ns[4]	P = 0.0166	ns
		High Calcareous Soils	
Nontreated	174	509	76
Water-Run MS 40 gpa	315	67	9
Shanked MS 40 gpa	697	239	39
SH +WR MS 80 gpa	542	22	26
Telone C-17	309	60*[5]	7
Tel 15 gpa + WRMS 30 gpa	Not Sampled	10	1
Pr > F	ns	ns	ns
Averaged over all treatments			
Low Calcareous Soil	77	11	3
High Calcareous Soil	364*	70*	15*
Pr > F	P = 0.0007	P = 0.0119	P = 0.0144

[1]October 13, 2008. Telone 15 gpa + WRMS 30 gpa not sampled initially because this treatment was not included on the original treatment list.
[2]February 16, 2009
[3]September 18, 2009
[4]Means with the same letter are not significantly different (P<0.05), ns = no significant differences.
[5]Significantly different from corresponding treatment in low calcareous soil (P<0.05).

Table 5b. Year two (2010) populations of root-lesion nematodes (*Pratylenchus neglectus*) (nematodes/250 g dry soil from 0-12 in.) in different fumigation treatments within low and high calcareous areas of potato fields.

Treatment	Prefumigation[1]	Post Fumigation[2]	Harvest[3]
		Low Calcareous Soils	
Nontreated	69	74	30
MS WR @ 40 gpa	37	4	2
MS Shank (40 gpa) & WR(40 gpa)	69	6	3
MS Shanked @ 40 gpa	69	16	34
Telone C-17 Shanked @ 22 gpa	14	4	36
MS Shanked @ 40 gpa	73	52	48
Telone II @ 20 gpa+MS @ 40 gpa	127	2	1
MS @ 40 gpa+sulfuric acid	119	2	3
Pr > F	ns[4]	ns	ns
		High Calcareous Soils	
Nontreated	78	73	20
MS WR @ 40 gpa	25	18	2
MS Shank (40 gpa) & WR(40 gpa)	114	44	32*
MS Shanked @ 40 gpa	138	123	123
Telone C-17 Shanked @ 22 gpa	78	69	50
MS Shanked @ 40 gpa	124	97	39
Telone II @ 20 gpa+MS @ 40 gpa	110	4	3
MS @ 40 gpa+sulfuric acid	56	25	18
Pr > F	ns	ns	ns
Averaged over all treatments			
Low Calcareous Soil	61	9	10
High Calcareous Soil	80	39*[5]	21
Pr > F	ns	P=0.0141	ns

[1]October 20, 2009.
[2]March 30, 2010
[3]September 24, 2010
[4]Means with the same letter are not significantly different (P<0.05), ns = no significant differences.
[5]Significantly different from corresponding treatment in low calcareous soil (P<0.05).

Table 6a. Year one (2009) populations of root-lesion nematodes (nematodes/250 g dry soil from 12-24 in.) in different fumigation treatments within low and high calcareous areas of potato fields.

Treatment	Prefumigation[1]	Post Fumigation[2]	Harvest[3]
	Low Calcareous Soils		
Nontreated	36	9	14
Water-Run MS 40 gpa	13	6	5
Shanked MS 40 gpa	6	3	3
SH +WR MS 80 gpa	39	0	3
Telone C-17	25	2	0
Tel 15 gpa + WRMS 30 gpa	Not Sampled	0	0
Pr > F	ns[4]	ns	ns
	High Calcareous Soils		
Nontreated	63	25	4
Water-Run MS 40 gpa	33	1	2
Shanked MS 40 gpa	144	19*	6
SH +WR MS 80 gpa	109	3	2
Telone C-17	58	7	4
Tel 15 gpa + WRMS 30 gpa	Not Sampled	24	1
Pr > F	ns	ns	ns
Averaged over all treatments			
Low Calcareous Soil	20	2	3
High Calcareous Soil	72*[5]	8*	3
Pr > F	P = 0.0056	P = 0.0523	ns

[1]October 13, 2008. Telone 15 gpa + WRMS 30 gpa not sampled initially because this treatment was not included on the original treatment list.
[2]February 16, 2009
[3]September 18, 2009
[4]Means with the same letter are not significantly different (P<0.05), ns = no significant differences.
[5]Significantly different from corresponding treatment in low calcareous soil (P<0.05).

Table 6b. Year two (2010) populations of root-lesion nematodes (*Pratylenchus neglectus*) (nematodes/250 g dry soil from 12-24 in.) in different fumigation treatments within low and high calcareous areas of potato fields.

Treatment	Prefumigation[1]	Post Fumigation[2]	Harvest[3]
	Low Calcareous Soils		
Nontreated	7	11	13
MS WR @ 40 gpa	7	2	1
MS Shank (40 gpa) & WR(40 gpa)	10	10	5
MS Shanked @ 40 gpa	15	19	30
Telone C-17 Shanked @ 22 gpa	4	3	17
MS Shanked @ 40 gpa	10	5	8
Telone II @ 20 gpa+MS @ 40 gpa	14	0	0
MS @ 40 gpa+sulfuric acid	15	2	2
Pr > F	ns[4]	ns	
	High Calcareous Soils		
Nontreated	11	14	4
MS WR @ 40 gpa	69	32	7
MS Shank (40 gpa) & WR(40 gpa)	22	11	4
MS Shanked @ 40 gpa	19	33	6
Telone C-17 Shanked @ 22 gpa	4	47	0*
MS Shanked @ 40 gpa	18	15	14
Telone II @ 20 gpa+MS @ 40 gpa	18	1	5
MS @ 40 gpa+sulfuric acid	4	23	2
Pr > F	ns	ns	ns
Averaged over all treatments			
Low Calcareous Soil	9	4	6
High Calcareous Soil	14	16*[5]	4
Pr > F	ns	P=0.0074	ns

[1]October 20, 2009.
[2]March 30, 2010
[3]September 24, 2010
[4]Means with the same letter are not significantly different (P<0.05), ns = no significant differences.
[5]Significantly different from corresponding treatment in low calcareous soil (P<0.05).

Table 7a. Year one (2009) populations of free-living nematodes (nematodes/250 g dry soil from 0-12 in.) in different fumigation treatments within low and high calcareous areas of potato fields.

Treatment	Prefumigation[1]	Post Fumigation[2]	Harvest[3]
		Low Calcareous Soils	
Nontreated	1,393	2,246 a[3]	1,002
Water-Run MS 40 gpa	1,292	452 bc	1,365
Shanked MS 40 gpa	2,242	1,147 ab	2,468
SH +WR MS 80 gpa	1,775	703 abc	1,249
Telone C-17	1,127	232 c	1,617
Tel 15 gpa + WRMS 30 gpa	Not Sampled	291 bc	2,053
Pr > F	ns[4]	P = 0.0356	ns
		High Calcareous Soils	
Nontreated	1,573	1,853 a	1,334
Water-Run MS 40 gpa	1,963	344 abc	2,195
Shanked MS 40 gpa	1,285	275 bc	2,197
SH +WR MS 80 gpa	1,935	117 c*[5]	1,563
Telone C-17	1,817	1,086 ab**	1,419
Tel 15 gpa + WRMS 30 gpa	Not Sampled	129 c	1,739
Pr > F	ns	P = 0.0265	ns
Averaged over all treatments			
Low Calcareous Soil	1,518	617	1,549
High Calcareous Soil	1,694	377	1,698
Pr > F	ns	ns	ns

[1]October 13, 2008. Telone 15 gpa + WRMS 30 gpa not sampled initially because this treatment was not included on the original treatment list.
[2]February 16, 2009
[3]September 18, 2009
[4]Means with the same letter are not significantly different (P<0.05), ns = no significant differences.
[5]Significantly different from corresponding treatment in low calcareous soil (* = P<0.05, ** = P <0.10).

Table 7b. Year two (2010) populations of free-living nematodes (nematodes/250 g dry soil from 0-12 in.) in different fumigation treatments within low and high calcareous areas of potato fields.

Treatment	Prefumigation[1]	Post Fumigation[2]	Harvest[3]
		Low Calcareous Soils	
Nontreated		939 a	304
MS WR @ 40 gpa	Not Counted	263 c	310
MS Shank (40 gpa) & WR(40 gpa)		401 abc	363
MS Shanked @ 40 gpa		351 bc	636
Telone C-17 Shanked @ 22 gpa		762 ab	268
MS Shanked @ 40 gpa		688 ab	403
Telone II @ 20 gpa+MS @ 40 gpa		376 abc	253
MS @ 40 gpa+sulfuric acid		723 ab	296
Pr > F		P = 0.0470	ns
		High Calcareous Soils	
Nontreated		763*[5]	299
MS WR @ 40 gpa	Not Counted	908	456
MS Shank (40 gpa) & WR(40 gpa)		721	377
MS Shanked @ 40 gpa		460	648
Telone C-17 Shanked @ 22 gpa		801	362
MS Shanked @ 40 gpa		437	592
Telone II @ 20 gpa+MS @ 40 gpa		1,128	297
MS @ 40 gpa+sulfuric acid		1,064	645
Pr > F		ns	ns
Averaged over all treatments			
Low Calcareous Soil		512	338
High Calcareous Soil		740*	427
Pr > F		P=0.0229	ns

[1]October 20, 2009.
[2]March 30, 2010
[3]September 24, 2010
[4]Means with the same letter are not significantly different (P<0.05), ns = no significant

differences.
[5]Significantly different from corresponding treatment in low calcareous soil (P<0.05).

Table 8a. Year one (2009) populations of free-living nematodes (nematodes/250 g dry soil from 12-24 in.) in different fumigation treatments within low and high calcareous areas of potato fields.

Treatment	Prefumigation[1]	Post Fumigation[2]	Harvest[3]
	Low Calcareous Soils		
Nontreated	1,520	264	849
Water-Run MS 40 gpa	1,320	232	1,262
Shanked MS 40 gpa	1,481	119	1,329
SH +WR MS 80 gpa	1,620	82	1,435
Telone C-17	950	105	1,470
Tel 15 gpa + WRMS 30 gpa	Not Sampled	64	1,862
Pr > F	ns[4]	ns	ns
	High Calcareous Soils		
Nontreated	895	425	587
Water-Run MS 40 gpa	1,150	103	600
Shanked MS 40 gpa	1,018	312	310
SH +WR MS 80 gpa	1,908	77	610
Telone C-17	1,114	195	485
Tel 15 gpa + WRMS 30 gpa	Not Sampled	137	1,258
Pr > F	ns	ns	ns
Averaged over all treatments			
Low Calcareous Soil	1,355	126	1,318
High Calcareous Soil	1,174	175	589*[5]
Pr > F	ns	ns	P = 0.0011

[1]October 13, 2008. Telone 15 gpa + WRMS 30 gpa not sampled initially because this treatment was not included on the original treatment list.
[2]February 16, 2009
[3]September 18, 2009
[4]Means with the same letter are not significantly different (P<0.05), ns = no significant differences.
[5]Significantly different from corresponding treatment in low calcareous soil (* = P<0.05).

Table.8b Year two (2010) populations of free-living nematodes (nematodes/250 g dry soil from 12-24 in.) in different fumigation treatments within low and high calcareous areas of potato fields.

Treatment	Prefumigation[1]	Post Fumigation[2]	Harvest[3]
		Low Calcareous Soils	
Nontreated		525 a[4]	285
MS WR @ 40 gpa	Not Counted	75 c	128
MS Shank (40 gpa) & WR(40 gpa)		258 abc	126
MS Shanked @ 40 gpa		168 abc	149
Telone C-17 Shanked @ 22 gpa		284 abc	237
MS Shanked @ 40 gpa		314 ab	115
Telone II @ 20 gpa+MS @ 40 gpa		108 bc	185
MS @ 40 gpa+sulfuric acid		241 abc	87
Pr > F		P = 0.0745	ns
		High Calcareous Soils	
Nontreated		446	101
MS WR @ 40 gpa	Not Counted	293	293
MS Shank (40 gpa) & WR(40 gpa)		177	341
MS Shanked @ 40 gpa		255	122
Telone C-17 Shanked @ 22 gpa		344	100
MS Shanked @ 40 gpa		202	199
Telone II @ 20 gpa+MS @ 40 gpa		231	85
MS @ 40 gpa+sulfuric acid		200	217
Pr > F		ns	ns
Averaged over all treatments			
Low Calcareous Soil		213	152
High Calcareous Soil		250	161
Pr > F		ns	ns

[1]October 20, 2009.
[2]March 30, 2010
[3]September 24, 2010
[4]Means with the same letter are not significantly different (P<0.05), ns = no significant differences.

Table 9a. Year one (2009) effect of field location on soil characteristics, pre & post potato crop.

Pre-Fumigation

Field	no3 lb./a	NH4 lb./a	P ppm	K ppm	S ppm	Ca meq/100g	Mg meq/100g	Na meq/100g	B ppm	Zn ppm
701	39.1a[1]	18.8a	25.4a	236.3a	16.6a	12.8a	1.7a	0.10a	0.29a	3.93a
718	61.4a	19.6a	20.7a	215.2a	29.5a	16.6a	2.0a	0.13a	0.42a	3.48a
721	23.9a	18.5a	20.5a	236.3a	12.1a	7.8a	1.6a	0.10a	0.18a	3.03a

Field	Mn ppm	Cu ppm	Fe ppm	pH	SS mmhos/cm	WP ppm	WK ppm	Cl ppm	CCE %	CEC meq/100g
701	5.4a	1.4a	18.0a	7.2a	0.2a	2.5a	22.7a	11.71a	0.58a	9.18a
718	6.3a	1.5a	16.4a	7.0a	0.3a	1.5a	22.7a	20.25a	4.21a	21.33a
721	6.9a	1.1a	24.1a	6.8a	0.1a	2.3a	24.8a	7.42a	0.29a	8.47a

Post Fumigation

Field	NO3 lb./a	NH4 lb./a	P ppm	K ppm	S ppm	Ca meq/100g	Mg meq/100g	Na meq/100g	B ppm	Zn ppm
701	47.3a	6.1b	31.8a	230.0a	111.2a	15.5a	1.8b	0.14b	0.53a	2.68ab
718	56.7a	6.7ab	24.5ab	165.7a	196.6a	21.5a	2.4a	0.20a	0.66a	3.12a
721	29.8a	7.9a	22.8b	197.4a	83.6a	8.8a	1.9ab	0.12b	0.57a	1.69b

Field	Mn ppm	Cu ppm	Fe ppm	pH	SS mmhos/cm	WP ppm	WK ppm	Sand %	Silt %	Clay %
701	5.7a	1.5a	22.3a	7.2a	0.5a	4.2a	34.3a	67.58a	25.30b	7.12a
718	4.6a	1.3a	16.6a	7.2a	0.6a	2.4a	23.9a	53.00a	37.80a	9.20a
721	7.1a	1.8a	24.9a	6.6a	0.3a	3.2a	25.4a	57.88a	36.24a	5.88a

[1]Numbers followed by the same letter are not significantly different ($P<0.05$)

Table 10a. Year one (2009) effect of soil calcium level on soil characteristics, pre & post potato crop.

Pre-Fumigation

SoilCa	no3 lb./a	nh4 lb./a	P ppm	K ppm	S ppm	Ca meq/100g	Mg meq/100g	Na meq/100g	B ppm	Zn ppm
High	60.4a[1]	19.7a	22.5a	224.5a	28.7a	18.4a	2.0a	0.12a	0.41a	3.42a
Low	22.5a	18.2a	21.9a	234.0a	10.1a	6.4a	1.6a	0.10a	0.17a	3.54a

SoilCa	Mn ppm	Cu ppm	Fe ppm	pH	SS mmhos/cm	WP ppm	WK ppm	Cl ppm	CCE %	CEC meq/100g
High	5.7a	1.5a	16.0a	7.4a	0.3a	1.5b	21.2a	9.28a	0.67a	15.34a
Low	6.8a	1.2a	23.0a	6.6a	0.1a	2.7a	25.6a	16.97a	2.71a	10.63a

Post Fumigation

SoilCa	NO3 lb./a	NH4 lb./a	P ppm	K ppm	S ppm	Ca meq/100g	Mg meq/100g	Na meq/100g	B ppm	Zn ppm
High	59.3a	8.2a	29.1a	221.1a	238.7a	22.4a	2.3a	0.17a	0.67a	2.83a
Low	29.8a	5.6b	23.7a	174.3a	22.2a	8.1a	1.8a	0.13b	0.49a	2.16a

SoilCa	Mn ppm	Cu ppm	Fe ppm	pH	SS mmhos/cm	WP ppm	WK ppm	Sand %	Silt %	Clay %
High	6.7a	1.8a	21.9a	7.1a	0.7a	2.3b	35.1a	49.03b	41.28a	9.69a
Low	4.9a	1.3a	20.7a	6.9a	0.2a	4.3a	20.7a	69.94a	24.94b	5.11a

[1]Numbers followed by the same letter are not significantly different ($P<0.05$)

Table 12a. Continued. Year one (2009) effect of fumigation treatment on soil characteristics, pre & post potato crop.

Treatment	Mn	Cu	Fe	pH	SS	WP	WK	Sand	Silt	Clay
	ppm	ppm	ppm		mmhos/cm	ppm	ppm	%	%	%
A	4.3b[1]	1.5a	16.7bc	7.3a	0.4bc	3.8a	25.8ab	59.25ab	33.28ab	7.47ab
B	4.5b	1.6a	19.0abc	7.1ab	0.5ab	3.2a	26.8ab	58.00ab	34.43ab	7.57ab
C	4.7ab	1.6a	18.8bc	7.1abc	0.4c	3.3a	27.0ab	61.58a	31.28b	7.13ab
D	3.8b	1.4a	16.5c	7.3a	0.6a	3.4a	37.5a	54.58b	37.38a	8.03a
E	8.7a	1.5a	29.5	6.6c	0.4bc	2.9a	20.8b	60.67ab	32.03ab	7.30ab
F	8.7a	1.7a	27.2ab	6.7bc	0.5ab	3.1a	29.2ab	62.83a	30.27b	6.90b

[1]Numbers followed by the same letter are not significantly different ($P<0.05$)

Treatment Code:

A - Control
B - Metam Sodium WR @ 40gpa
C - Metam Sodium Shanked @ 40gpa
D - Metam Sodium Shanked (40gpa) and WR (40gpa)
E - Telone C-17 @20gpa
F - Telone @ 15 gpa + Metam Sodium WR @ 40gpa

Table 13. Year 2 (2010) Main effects (soil pH) for soil nutrient analysis at the 0-1 foot depth

	B		Ca		Cu		Fe		K		Mg		Mn	
Main effect	Ppm		Meq		ppm		ppm		ppm		Meq		ppm	
Low pH	0.18	B	5.4	B	0.88	A	28.8	A	303	A	2.02	A	7.3	A
High pH	0.25	A	15.1	A	0.69	A	30.5	A	264	A	1.31	A	14.0	A

	NH4		NO3		Na		P		S		SS		WSK		WSP	
	Lb/a		Lb/a		Meq		Ppm		ppm		mmhos		ppm		ppm	
Low pH	16	A	174	A	0.11	A	20	A	13.4	B	0.34	B	51.0	A	2.07	A
High pH	33	A	140	A	0.10	A	27	A	163.5	A	0.69	A	59.3	A	1.96	A

Numbers followed by different letters are significantly different at p=0.10 using LSD.

Treatments:
1 - Untreated Control
2 - MS WR @ 40 gpa
3 - MS Shanked (40gpa) and WR (40gpa)
4 - MS Shanked @ 40 gpa
5 - Telone C-17 Shank @ 22 gpa
6 - MS Shanked @ 40 gpa
7 - Telone II @20 gpa+MS @ 40 gpa
8 - MS 40 @ gpa+ Sulfuric Acid

Table 14. Year 2 (2010) soil pH post fumigation by treatment for each field.

	Low pH			High pH		
	Field			Field		
Treatment	1	2	3	1	2	3
1	6.0	6.0	6.2	7.5	7.5	5.3
2	5.5	5.7	5.8	7.1	7.4	4.5
3	5.8	5.9	5.8	7.5	7.4	4.5
4	5.8	5.8	5.9	7.4	7.2	4.5
5	5.5	5.8	5.8	7.3	7.3	4.6
6	6.3	6.2	6.3	7.6	7.6	4.4
7	5.7	5.9	5.8	7.3	7.4	4.5
8	5.8	5.8	5.7	7.3	7.4	4.4
Average	5.8	5.9	5.9	7.4	7.4	4.6

Treatments:

1 - Untreated Con troll
2 - MS WR @ 40 gpa
3 - MS Shanked (40gpa) and WR (40gpa)
4 - MS Shanked @ 40 gpa
5 - Telone C-17 Shank @ 22 gpa
6 - MS Shanked @ 40 gpa
7 - Telone II @20 gpa+MS @ 40 gpa
8 - MS 40 @ gpa+ Sulfuric Acid

Table 15. Year two (2010) treatment effects were analyzed and are listed in the below table.

Treatment	B ppm		Ca Meq		Cu ppm		Fe ppm		K ppm		Mg Meq		Mn ppm	
1	0.21	AB	11.9	AB	0.73	B	21.3	B	269	BC	1.57	C	5.7	B
2	0.22	AB	9.1	C	0.78	AB	33.0	A	311	A	1.63	BC	15.0	A
3	0.20	B	12.7	A	0.81	A	29.3	AB	250	C	1.64	ABC	9.5	AB
4	0.21	AB	8.4	C	0.80	AB	29.7	AB	290	AB	1.70	AB	9.3	AB
5	0.21	AB	10.1	BC	0.78	AB	29.2	AB	295	A	1.72	AB	8.8	AB
6	0.23	A	12.2	AB	0.77	AB	29.7	AB	266	BC	1.67	AB	12.5	A
7	0.22	AB	9.4	C	0.80	AB	30.0	AB	297	A	1.73	A	10.7	AB
8	0.22	AB	8.3	C	0.77	AB	35.0	A	290	AB	1.63	BC	13.5	A

Treatment	NH4		NO3		Na		P		S		SS		WSK		WSP	
1	13	B	144	BC	0.10	A	19	D	90.2	BC	0.48	BC	43.5	B	1.62	C
2	38	A	174	AB	0.12	A	25	AB	99.7	AB	0.58	AB	68.0	A	2.22	AB
3	23	AB	132	CD	0.10	A	21	BCD	130.2	A	0.59	A	43.7	B	1.43	C
4	16	AB	195	A	0.10	A	25	AB	80.3	BC	0.52	AB	58.5	A	2.20	AB
5	16	AB	171	AB	0.10	A	24	ABC	79.7	BC	0.50	ABC	58.8	A	2.30	A
6	31	AB	108	D	0.10	A	21	CD	63.5	C	0.40	C	44.8	B	1.77	BC
7	22	AB	174	AB	0.10	A	24	ABC	88.5	BC	0.58	AB	62.0	A	2.15	AB
8	37	A	157	BC	0.12	A	28	A	75.5	BC	0.48	BC	61.5	A	2.42	A

Numbers followed by different letters are significantly different at p=0.10 using LSD.

Treatments:

1 - Untreated Control
2 - MS WR @ 40 gpa
3 - MS Shanked (40gpa) and WR (40gpa)
4 - MS Shanked @ 40 gpa
5 - Telone C-17 Shank @ 22 gpa
6 - MS Shanked @ 40 gpa
7 - Telone II @20 gpa+MS @ 40 gpa

8 - MS 40 @ gpa+ Sulfuric Acid

Table 16. Year two (2010) soil pH for treatments for both the high pH and low pH fields.

Treatment	Low pH	High pH
1	6.1	6.8
2	5.7	6.3
3	5.8	6.5
4	5.8	6.4
5	5.7	6.4
6	6.3	6.5
7	5.8	6.4
8	5.8	6.4

Treatments:

1 - Untreated Con troll
2 - MS WR @ 40 gpa
3 - MS Shanked (40gpa) and WR (40gpa)
4 - MS Shanked @ 40 gpa
5 - Telone C-17 Shank @ 22 gpa
6 - MS Shanked @ 40 gpa
7 - Telone II @20 gpa+MS @ 40 gpa
8 - MS 40 @ gpa+ Sulfuric Acid

Figure 1. Effect of soil pH on Zinc, Copper and water soluble P for post fumigation soil samples in year two.

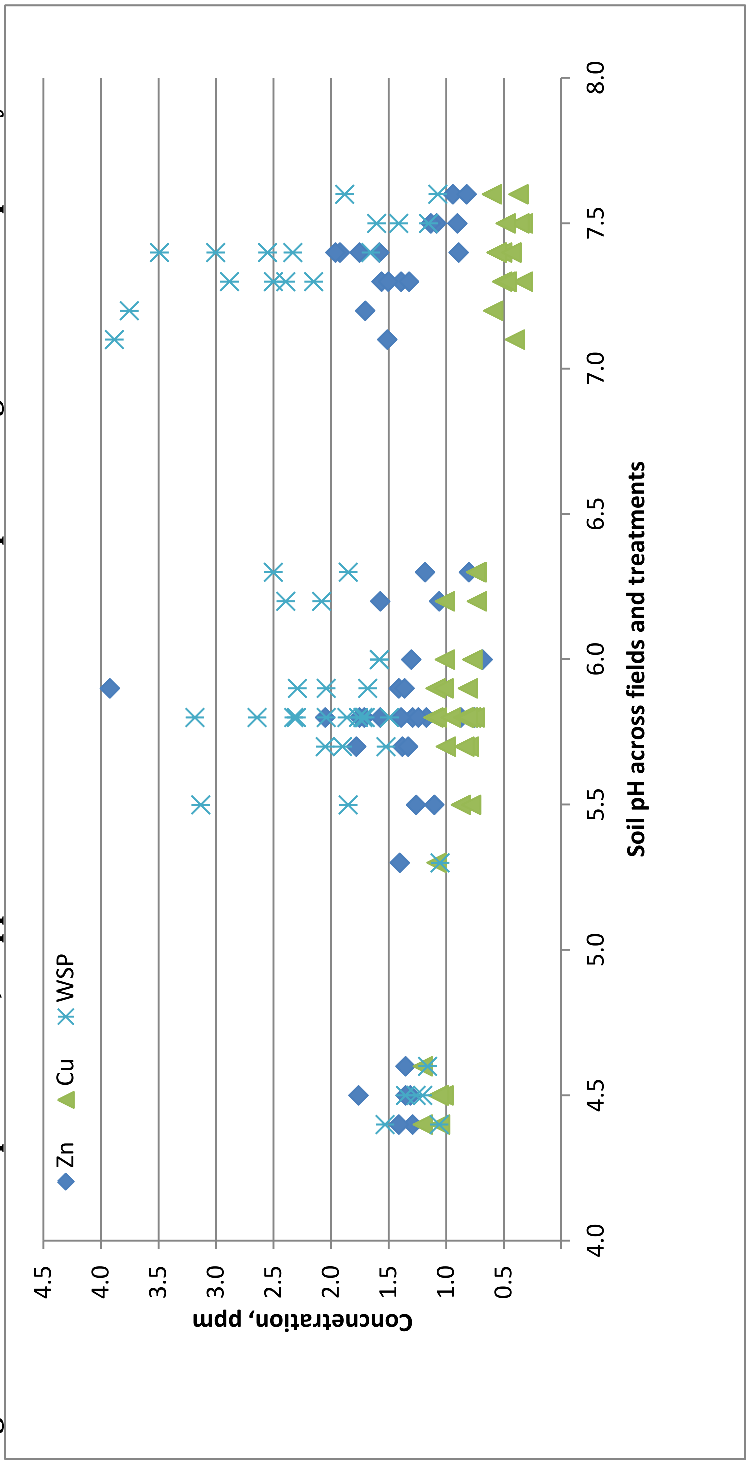

Figure 2. Effect of soil pH on soil Manganese and Iron in year two for post fumigation soil samples.