ON-19
2000

SOIL pH CHANGES WITH SURFACE BROADCAST AND INCORPORATED LIME

Report to the Potash & Phosphate Institue of Canada
October 2000

J.D. Gaynor and D.S. Young
GPCRC, AAFC Harrow, ON and U of Guelph, Ridgetown, ON

Abstract: Lime, to optimize soil pH for crop growth, has traditionally been incorporated to increase its rate of reaction and depth of influence. No-till requires a change in cultural practice to accommodate soil tillage treatments. We investigated the effects of tillage on the rate and depth of reaction of dolomitic and pelletized lime at three sites in Southwestern Ontario. Crop response to starter and Mn was also included in the study. Rain was below normal during the duration of the study. This had a negative effect on detecting differences between tillage treatments on rate and depth of reaction of the lime. At Thamesville, lime, cultivation, starter and Mn addition had no effect on soybean or corn yield. An increase in soil pH by lime addition was only detected on three of the nine sampling dates. Soil extractable manganese and manganese concentration in plant tissue were not affected by any of the treatments. There was a lime, cultivation and starter effect on soil extractable P and concentration in soybean. Lime increased soil pH to 5.0 cm depth in the clay soil at Woodslee. Lime decreased corn but had no affect on soybean yield probably because pH in the root zone was not changed by lime. None of the treatments altered soil extractable P but dolomitic lime increased P uptake in soybean while pelletized lime decreased uptake. Tillage decreased extractable K 16 to 20% from no-till in 1998 and starter increased extractable K 18% from no starter in 1999 . at Melbourne, lime increased soil pH to 5 cm in tilled but only to 2.5 cm in no-till plots in the sandy loam. Lime increased soybean yield but no-till decreased corn yield. None of the treatments affected P in soil or plant tissue. Extractable Mn in soil was increased by starter but lime decreased Mn uptake in both soybean and corn. None of the sites appeared to be deficient in P, K, Mn or Zn since tissue concentrations were greater than the critical levels. Rain appears critical to the effectiveness of surface applied lime to neutralize soil acidity in clay and sandy loam soil. Starter can overcome some of the negative effects of soil acidity on yield in a clay soil.

INTRODUCTION

The adoption of conservation tillage to reduce soil erosion poses management problems associated with past tillage practices. Traditionally, soil acidity was neutralized by incorporating lime into the root zone to enhance its interaction with soil and provide a conducive environment for plant growth and biochemical activities. Soil acidity has been associated with reduced nodulation and root growth of legumes (Sartain and Kamprath, 1975). Soybean yield on no-till and conventional till in Brazil was increased by surface applied dolomite because of a decrease in Al and increase in Ca and Mg (de Oliveira and Pavan, 1996). Moschler et al. (1973) found higher yield increase of corn on no-till limed soil than conventionally tilled limed soil. The increased yield was attributed to better early growth and water use efficiency associated with no-till.

The availability of plant nutrients in soil is affected by pH. Uptake of metal ions decreases as soil becomes more alkaline in reaction (Krebs et al., 1998). Manganese availability decreases as pH increases and P is most available at a neutral pH (Tisdale and Nelson, 1968). Deficiencies of these elements can be overcome by band application of a starter fertilizer or foliar application of micronutrients.

The study was initiated at three sites in the fall of 1997 to compare efficacy of incorporated and surface applied lime on soybean yield. Changes in soil pH were recorded at selected times during the growing season from lime application in spring 1998 to after harvest in 1999. Depth of interaction of the lime was also measured. We compared two forms of lime (pelletized and dolomitic limestone) for its rate and depth of reaction in soil as well as the effect of lime on starter fertilizer, with and without foliar applied Mn.

MATERIALS AND METHODS

Sites

Three sites were selected in southwestern Ontario based on initial pH less than 5 at 0 to 15 cm depth. The site at Woodslee is a Brookston clay with initial pH 5.3 (Table 1). The grower reported reduced yields attributed to low pH. The Thamesville site was a Berrien sandy loam susceptible to wind erosion with initial pH 5.7. A Brookston sandy loam located east of Melbourne had an initial pH of 4.9 at 0 to 15 cm. Selected chemical properties of the soils are reported in Table 1. The chemical constituents cannot be compared among sites since analyses were performed at different laboratories with their own procedures. Samples from the Woodslee site were analysed at Stratford Agri-Analysis in Stratford, ON, those from Thamesville at A&L Laboratories East, Inc, London, ON and those from Melbourne at Agri-Food Laboratories Ltd., in Guelph, ON.

Treatments

The treatments were randomized in a split-split plot design to include 72 plots of 3 by 12 m each. Main plots were tillage with lime split within tillage and starter split within lime. There were four replicates at each site. Cultivated plots were tilled in spring with two passes of a disc. The non cultivated treatments had no tillage except that associated with the John Deere 7000, Maximerge planter. The planter had two fluted coulters followed by Dawn^R trashwheels in front of the seed opener. Lime at 5 t/ha was applied with a Gandy applicator. Starter (0-30-70 kg/ha, N-P_2O_5-K_2O) was applied in a 5 by 5 cm band to the side and below the seed at planting. Manganese (8 kg/ha) as $MnSO_4$ was applied at flowering to soybean and at the 7 to 8 leaf stage in corn. Soybean (Westag 97) was planted in 1998 at 444,600 seeds/ha and corn was planted at 74,150 seeds/ha in 1999. Corn cultivars were selected based on heat units for each area. Corn was fertilized with nitrogen as 28% UAN solution in mid-June. Nitrogen was applied at a rate of 180 kg N/ha. Planting, harvest and sampling dates are shown in Table 2.

Soil sampling

Ten soil cores from four depths (0 to 2.5, 2.5 to 5.0, 5.0 to 10 and 10 to 20 cm) were composited from each plot for pH determination. Samples were taken with a 2.5 cm dia probe fitted with an acetate sleeve. There were six sampling dates in 1998 and four in 1999 (Table 2). Samples were sectioned, mixed, subsampled, bagged and boxed in the field prior to transport to the analytical laboratory.

Soil samples from 0 to 15 cm deep were taken from each plot at three times during the study (Table 2). These samples provided data comparable to what a grower would take for fertilizer recommendation and nutrient determination. A communication error between cooperators resulted in loss of data at Thamesville for the second sample at 0 to 15 cm depth in 1998 and no after harvest sample for pH in 1999.

Soil analysis

Sufficient distilled water was added to soil to form a saturated paste without visible free water on the surface. The paste mixture was allowed to equilibrate 15 to 20 min before pH was determined with a pH metre while slowly moving the glass electrode through the paste. Plant available P was estimated from a Na_2HCO_3 extract of soil according to Olson et al (1954). Potassium (Heluke and Sparks, 1996), Mg and Ca (Suarez, 1996) were extracted in NH_4OAc, extractable Zn in DTPA and Mn in H_3PO_4 (Grambrell, 1996). Organic matter was determined from procedures described by Walkely and Black (1934) or Leco induction furnace (Nelson and Sommers, 1996).

Tissue sampling

Soybean leaves were collected at flowering (top fully expanded trifoliate) and corn at silking (mid one-third of ear leaf) for tissue analyses. Samples from individual plots were composited, bagged and transported to the laboratory for analyses. Plant material was dried, ground and digested in HCl for chemical analyses.

Data analysis

All data was analysed as a split-split plot design using PROC ANOVA (SAS, 1982). Each main effect and interaction was tested against its appropriate error term. Differences in pH among depths of sampling was assessed with PROC NESTED procedure of SAS.

RESULTS AND DISCUSSION

Rain at the three sites was below normal in both years of the study (Table 3). More rain was received at Melbourne and Thamesville than at Woodslee. The lower than normal rain would reduce the rate of reaction of lime as well as the depth of reaction in soil. In May 1998, only half as much rain (23 mm) was received at Woodslee than at Melbourne (45 mm) and Thamesville (53 mm). All sites received similar rain in June and July with August and September being wettest at Melbourne and driest at Thamesville. During the growing season from May to September 1999, Melbourne received less rain (169 mm) than Thamesville (194 mm) and Woodslee (207 mm). The study was not designed to detect differences among sites because of differences in growing season and separate analytical laboratories were used for chemical analyses. Therefore results are discussed by site with limited comparisons between sites.

Extractable P and K varied between the three sites (Table 1). Sodium bicarbonate extractable P was high at Thamesville and Melbourne (>92 ppm) and low at Woodslee (12 to 15 ppm). Except for Woodslee, the high extractable P concentration indicate an excess of this element. The sufficiency level for P is 20 ppm (OMAFRA, 1994) thus a response to P may only be expected at Woodslee. Sufficiency level for K is 121 ppm and all sites were below this concentration. Application of dolomitic lime is recommended at the Thamesville and Melbourne sites since extractable Mg was below 100 ppm. The Zn and Mn indicies indicate these elements are available in adequate amounts in these soils but availability could be affected by lime treatment.

Thamesville

Soil pH at the Thamesville site was > pH 5.6 on date 1 (Figure 1) which was unexpected based on preliminary results. However, soil pH significantly decreased with depth for all sampling dates ($p<0.001$) and was less than pH 5.6 at depths greater than 5 cm. Lime and cultivation had no effect on pH at depths greater than 5 cm. Lime increased pH in the 0 to 2.5 cm depth on sampling dates 4 (Jul 1998), 5 (Aug 1998) and 9 (Jun 1999) but not on other dates (Table 4). Soil pH was higher in the 0 to 2.5 cm depth from limed than unlimed treatments in no-till but there were no differences in pH between unlimed and limed treatment at this depth when incorporated by disc. The drop in pH on sample date 9 (Jun 1999) may be from acidifying effect of carbon dioxide release from microbial activity. A smaller decrease in pH was noted on date 6 (Oct 1998) compared to previous samples indicating seasonal or annual variations in microbial activity. Soil pH has previously been reported to decrease in fall because of carbon dioxide from microbial activity during the summer months.

Neither soybean (1998) nor corn (1999) yield was affected by treatment at Thamesville (Tables 5 and 6). Soybean yield averaged 2.5 t/ha and corn yield 6.5 t/ha. The average yield for these crops in Kent county for 1998 was 3.2 t/ha for soybean and for 1999, 8.8 t/ha for corn. The lack of a lime response to yield could be related to no change in pH by lime at depths greater than 5 cm compared to the control without lime addition and that pH at 0 to 2.5 cm was greater than 5.6.

Lime has an affect on availability of nutrients in soil and plant uptake. A tillage by lime by starter interaction was detected for soil extractable P ($p<0.01$) in 1998 (Table 7). As expected, starter increased extractable P in the no lime and dolomitic lime treatments compared to no starter treatment (Table 8) . Starter had no effect on extractable P in the pelletized lime treatment. Extractable P was higher from no-till than till treatments.

Concentration of selected nutrients in soybean are reported in Table 9. Dolomitic and pelletized lime increased concentration of P in soybean grown on no-till treatments but plant P was only increased with pelletized lime on tilled treatments ($p<0.04$) (Table 10). There was no change in extractable Mn in soil and in plant tissue from any of the treatments ($p>0.05$). No-till decreased uptake of Mg 18% in corn ($p<0.01$) compared to tilled (0.26 ppm). Starter increased uptake of P and K but decreased uptake of Mg, Ca and Cu. The concentrations were still greater than the critical concentrations consequently yield would not be expected to be reduced. A starter by tillage interaction was found for Zn where lower Zn concentrations were found in corn from no-till with starter than conventional till and no starter.

Woodslee

Soil pH was significantly higher in the 0 to 2.5 cm depth than at deeper depths ($p<0.001$) (Table 11). Lime increased pH in the 0 to 2.5 and 2.5 to 5.0 cm depths compared to the no lime treatment (Figure 2). There was a significant effect of cultivation ($p<0.03$) in the 0 to 2.5 and 2.5 to 5.0 cm depths for the last sample date (D 10, Oct 1999) only. Soil pH in the 2.5 to 5.0 cm depth was raised more in the tilled than no-till treatment indicating that the below normal rainfall was not as effective as tillage in moving the lime from the surface to greater depths. Soil pH in the limed treatments decreased from the 7th (May 1999) to the 8th (Jun 1999) sampling date probably because of an increase in microbial activity which respired CO_2.

Soybean (1998) and corn (1999) yield was decreased by lime but the yield decrease (14%) was only significant ($p=0.05$) in corn (Tables 5 and 6). Yield of both corn and soybean was significantly increased (37 and 31%) by starter ($p<0.01$). A response to starter would be expected since soil P and K was less than the sufficiency level for maximum yield (Table 1). Visual K leaf deficiency symptoms were observed for both corn and soybeans in each of the two years of study at Woodslee. Yield at this site (1.9 and 3.8 t/ha for soybean and corn, respectively) was below the county average (3.0 and 7.9 t/ha for soybean and corn, respectively) because of the lack of rain. Tillage had no affect on crop yield.

Less extractable Mn (20 to 35%) and K (16 to 20%) was found in the tilled than the no-till treatments in soil samples from May and Jun 1998 ($p<0.05$) but not the Nov 1999 samples (Table 11). No-till is associated with higher soil water content (Potter et al., 1985; Stone et al., 1989; Drury et al., 1999) which may account for the larger Mn concentrations in this treatment. Extractable soil Mn is higher in soil at higher soil water content (Tisdale and Nelson, 1968). In 1999, lime increased extractable Mg and Ca as expected. More extractable Zn was found in no-till (23%) than till (0.96 ppm) treatment. Starter increased extractable K 18% compared to the no starter (87 ppm) treatment.

Nutrient concentrations of selected elements averaged over all treatments are reported in Table 9 for soybean and corn. Manganese in soybean tissue was increased ($p<0.01$)from 59 mg/kg to 71 and 70 mg/kg by starter and starter + Mn, respectively (Table 13). Potassium uptake was also increased by starter but Ca, Mg, and Zn concentration in soybean were decreased compared to the no starter treatments. A lime by starter interaction was found for P, K, Ca and Zn concentration in soybean. Concentration of these elements in soybean were greater than the critical level for this crop. Starter and starter + Mn increased K 45% but decreased Mg 28% in corn. Manganese concentration decreased ($p<0.01$) from 66 mg/kg where no lime was added to 58 and 60 mg/kg with dolimitic and pelletized lime. We were not able to detect any change in extractable Mn from soil ($p>0.05$) as a result of Mn addition thus it appears that H_3PO_4 extractable Mn in soil was not a good index for Mn uptake although the poor correlation may relate to there being sufficient Mn in this soil (Table 1). None of the treatments had any measurable effect on soil extractable P ($p>0.05$) (Table 12). In soybean tissue, there was a starter by lime interaction for P ($p=0.05$). In the presence of starter, pelletized lime decreased P concentration in soybean 9% (from 0.35 mg/kg) but dolomitic lime increased P concentration 9% (from 0.33 mg/kg). In the absence of lime, starter decreased P concentration in the plant 12% compared to the treatment without starter (0.33 mg/kg).

Melbourne

Soil pH significantly decreased with depth at Melbourne ($p<0.001$) (Figure 3). Lime increased soil pH in both the 0 to 2.5 and 2.5 to 5.0 cm depths ($p<0.03$) (Table 14). Soil pH in the 2.5 to 5.0 cm depth was higher in the limed treatments than the unlimed treatment in tilled soil compared to the no-till treatment but the differences between tillage treatments at this depth were not significant ($p>0.05$). There was no difference in soil pH between no-till and tilled treatment indicating there was sufficient rain to activate the lime to deeper depth.

Lime increased soybean (17%) ($p<0.01$) but not corn yield (Tables 5 and 6). No-till decreased corn yield 15% from tilled (9.3 t/ha). A reduction in corn yield from no-till has been observed by others and is attributed to cooler soil temperatures and poorer germination from the higher water content associated with this tillage practice (Potter et al., 1985; Drury et al., 1999). Both soybean and corn yield were lower (2.0 and 8.6 t/ha, respectively) than the average yields for Middlesex county (3.0 and 9.5 t/ha, respectively). There was a tillage by lime interaction for corn yield ($p<0.05$) (Table 6).

Soil extractable Mn was increased by starter and starter + Mn ($p=0.05$) in the soil samples collected in May and Jun 1998 but not Nov 1999 (Table 16). Without starter, soil Mn averaged 7.2 and 9.5 mg/kg, respectively in May and Jun. Starter and starter + Mn increased extractable Mn by 13 and 25%, respectively in May and 14 and 13%, respectively in Jun 1998. Less extractable K was found in no-till than tilled soil at the Jun 1998 date. Soil P was not affected by any of the treatments ($p>0.05$) (Table 15). In 1999, extractable Mg and Ca were increased by lime treatment.

There was a lime by tillage interaction for K concentration and a lime by starter interaction for Zn concentration in soybean. Nutrient concentration in soybean and corn averaged over all treatments were above critical levels for these elements(Table 9). Dolomitic lime decreased ($p<0.05$) (Table 16) Mn concentration 16% while pelletized lime increased concentration of this element 6% in soybean over no lime (161 mg/kg). In corn, both forms of lime decreased ($p<0.05$) Mn concentration 17 to 19% from the control without lime (165 mg/kg). Phosphorus uptake was not affected by any of the treatments.

CONCLUSIONS

Lime, starter, Mn and tillage affected yield, soil extractable nutrients and plant tissue concentration in different ways at each site. Crop yield responded to lime in a positive way at Melbourne on Brookston sandy loam but negatively at Woodslee on Brookston clay. Tillage had a greater affect on crop yield on the sandy loam at Melbourne than at the other sites. The Berrien sandy loam at Thamesville did not respond to any of the treatments. The reduction in corn yield with no-till at Melbourne is consistent with other reports as is the lack of a response to tillage at Woodslee. It has been observed that no-till may increase, decrease or have no affect on crop yield on clay loam, depending on the growing season (Drury et al., 1996). The form of lime (dolomitic or pelletized) did not seem to affect the rate or depth of reaction of the lime. Dolomitic lime would be recommended for the Melbourne and Thamesville sites since soil extractable Mg was less than 100 ppm. The lack of a consistent response of tillage to lime at all sites may in part be attributed to the below normal rainfall during the time of the study. This is evident from the data in that most of the changes in pH occurred in the 0 to 2.5 cm depth of soil. Incorporation of lime by disc would mix the lime in the top 4 or 5 cm of soil as evident by differences in pH between limed and unlimed treatments in the top two depths at Melbourne and Woodslee. The lack of a positive response to lime at Woodslee may relate to the higher acidity in the root zone since lime did not penetrate below 5 cm whereas at Melbourne, where a response was noted, lime may have reached 10 cm with incorporation.

The lack of a response to Mn and P at Melbourne and Thamesville may indicate these nutrients were not limiting (Tables 1 and 9) except at Woodslee where a response to starter was detected. Phosphorus concentrations in soil at Melbourne and Thamesville but not Woodslee were well above the 20 ppm sufficiency level. The Mn index for these soils and tissue concentrations suggest this element was sufficient for good crop growth except possibly at Thamesville. No Mn deficiency symptoms were evident at any of the sites although some treatments showed K deficiency. Base saturation of K was below 3.2 in the limed treatments without starter at Woodslee but not at the other sites. Base saturation of K below 3.2 has been associated with poor soybean growth.

ACKNOWLEDGEMENT

Appreciation is expressed to The Fertilizer Institute of Ontario, The Canadian Fertilizer Institute, The Potash and Phosphate Institute, Stratford Agri-Analysis Inc., A&L Laboratories, Inc., Agri-Food Labs, Setterington's Fertilizer Service Ltd., the cooperating growers and the Matching Investment Initiative Program of AAFC for financial, analytical and resource support. Technical support was provided by M. Zink, D. MacTavish, J. St.Denis, R. Edwards, the Woodslee and University of Guelph, Ridgetown farm crews and many summer students.

REFERENCES

de Oliveira, E.L. and M.A. Pavan. 1996. Control of soil acidit in no-tillage systeem for soybean production. Soil Tillage Res. 38:47-57.

Drury, C.F., D.J. McKenney, W.I. Findlay and J.D. Gaynor. 1993. Influence of tillage on nitrate loss in surface runoff and tile drainage. Soil Sci. Soc. Amer. J. 57:797-802.

Drury, C.F., C.S. Tan, T.W. Welacky, T.O. Oloya, A.S. Hamill and S.E. Weaver. 1999. Red clover and tillage influence on soil temperature, water content, and corn emergence. Agron. J. 91:101-108.

Fageria, N.K and V.C. Baligar. 1999. Growth and nutrient concentrations of common bean, lowland rice, corn, soybean and wheat at different soil pH on an inceptisol. J. Plant Nutr. 22; 1495-1507.

Gambrell, R.P. 1996. Manganese. P. 665-682. In D.L. Sparks (ed.) Methods of soil analysis, Part 3, SSSA Book series No. 5, Madison, WI.

Helmke, P.A. and D.L. Sparks. 1996. Lithium, sodium, potassium, rubidium and cesium. P. 551-574. In D.L. Sparks (ed.) Methods of soil analysis, Part 3, SSSA Book series No. 5, Madison, WI.

Krebs, R., S.K. Gupta, G. Furrer and R. Schulin. 1998. Solubility and plant uptake of metals with and without liming of sludge-amended soils. J. Environ. Qual. 27:18-23.

Moschler, W.W., D.C. Martens, C.I. Rich and G.M. Shear. 1973. Comparative lime effects on continuous no-tillage and conventionally tilled corn. Agron. J. 65:781-783.

Nelson, D.W. and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. P. 961-1010. In D.L. Sparks (ed.) Methods of soil analysis, Part 3, SSSA Book series No. 5, Madison, WI.

Olsen, S.R., C.V. Coles, F.S. Watanabe and L.A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular No. 939, Washington, DC.

Ontario Ministry of Agriculture, Food and Rural Affairs. 1995. 1995-1996 Field crop recommendations. Queens printer Toronto, ON

Potter, K.N., R.M. Cruse and R. Horton. 1985. Tillage effects on soil thermal properties. Soil Sci. Soc. Amer. J. 56:968-973.

Sartain, J.B. and E.J. Kamprath. 1975. Effect of liming a highly Al-saturated soil on hte top and root growth and soybean nodulation. J. Agron. 67:507-510.

Stone, J.A., T.J. Vyn, H.D. Martin and P.H. Groenevelt. 1989. Ridge-tillage and early-season soil moisture and temperature on a poorly drained soil. Can J. Soil Sci. 69:181-186.

Suarez, D.L. 1996. Beryllium, magnesium, calcium, strontium and barium. P. 575-601. In D.L. Sparks (ed.) Methods of soil analysis, Part 3, SSSA Book series No. 5, Madison, WI.

Tisdale, S.L. and W. L. Nelson. 1967. Soil Fertility and Fertilizers. 2nd ed. The MacMillan Company, NY

Walkley, A. and I.A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci. 37:29-38.

Table 1. Nutrient analysis of soil (0 to 15 cm depth) from three sites in Ontario averaged over all treatments.

Date	pH	OM, %	P, ppm	K, ppm	Mg, ppm	Ca, ppm	Zn, ppm	Mn, ppm	CEC, meq/100 g	Fe, ppm	Cu, ppm	Mn index-	Zn index-
	Melbourne												
1998*	4.88	3.21	153	87	41	319	5.9	8.2	3.4	nd	nd	62	62
1998	4.82	3.43	185	105	51	298	5.6	10.2	3.4	nd	nd	65	61
1999	4.88	3.38	128	100	81	418	5.2	8.9	nd	nd	nd	30	44
	Thamesville												
1998	5.65	2.23	92	60	77	291	2.1	2.8	nd	nd	nd	28	31
	Woodslee												
1998	5.29	3.24	14	92	224	876	1.1	5.0	17.0	141	0.74	45	33
1998	5.33	3.10	12	85	258	942	1.0	3.5	7.1	142	0.77	44	33
1999	5.13	3.39	15	98	291	998	1.1	4.7	nd	nd	nd	44	33
	Sufficiency level												
	>5.6		>20	>121	>100							>30	>25

-Index calculated from extractable soil Mn or Zn and pH nd=not determined

*For Melbourne and Woodslee the first 1998 row is before lime addition and the second 1998 row is one month after lime addition.

Table 2. Planting, harvest and sampling dates for pH, soil nutrients (0 to 15 cm) and plant tissue at three sites in Ontario

Event	Melbourne	Thamesville	Woodslee
Planted	May 26, 1998	May 22, 1998	May 27, 1998
	May 12, 1999	May 12, 1999	May 11, 1999
pH, D1	May 6, 1998	Apr 30, 1998	Oct 29, 1997
D2	Jun 4, 1998	Jun 3, 1998	Jun 2, 1998
D3	Jun 22, 1998	Jun 23, 1998	Jun 24, 1998
D4	Jul 20, 1998	Jul 24, 1998	Jul 14, 1998
D5	Aug 20, 1998	Aug 19, 1998	Aug 18, 1998
D6	Oct 15, 1998	Oct 14, 1998	Oct 13, 1998
D7	May 10, 1999	May 11, 1999	May 3, 1999
D8	Jun 8, 1999	Jun 9, 1999	Jun 7, 1999
D9	Jul 5, 1999	Jun 28, 1999	Jun 30, 1999
D10	Oct 26, 1999	No sample	Oct 28, 1999
Soil	May 6, 1998	Apr 29, 1998	May 27, 1998
	Jun 17, 1998	No sample	Jun 16, 1998
	Nov 10, 1999	No sample	Nov 9, 1999
Tissue	Aug 4, 1998	Aug 15, 1998	Aug 10, 1998
	Jul 28, 1999	Jul 30, 1999	Jul 27, 1999
Harvest	Sep 30, 1998	Sep 25, 1998	Sep 24, 1998
	Oct 2, 1999	Oct 4, 1999	Oct 7, 1999

Table 3. Rain at Woodslee, Melbourne and Thamesville 1998 and 1999

Year	Period or Month	Melbourne	Thamesville	Woodslee
		Rain, mm		
1998	Jan to May	250	279	282
	May	45	53	23
	Jun	44	45	49
	Jul	78	83	71
	Aug	174	83	128
	Sep	53	28	25
	Annual	788	662	648
1999	Jan to May	NA	221	208
	May	34	21	41
	Jun	62	52	60
	Jul	10	42	19
	Aug	18	36	52
	Sep	45	43	35
	Annual	NA	600	481
	10 yr average	848	776	763

Table 4. Probability of greater F statistic for soil pH at four depths (1=0 to 2.5 cm, 2=2.5 to 5.0 cm, 3=5 to 10 cm, 4=10 to 20 cm) and nine sampling dates ((see Table 1 for dates) at Thamesville

Depth	Attribute	D1	D2	D3	D4	D5	D6	D7	D8	D9
		Probability of greater F								
1	Lime(L)	0.43	0.59	0.24	<0.01	<0.01	0.09	0.08	0.1	0.02
1	Tillage(T)	0.41	0.2	0.12	0.79	0.16	0.42	0.04	0.06	0.41
1	Starter(S)	0.75	<0.01	0.07	0.14	0.04	0.01	0.16	0.06	<0.01
1	L*S	0.09	0.53	0.5	0.8	0.34	0.22	0.27	0.23	0.15
1	L*T	0.01	0.79	0.47	0.36	0.02	0.08	0.49	0.23	0.72
1	S*T	0.47	0.06	0.11	0.54	0.57	0.43	0.51	0.13	0.81
1	L*S*T	0.9	0.74	0.08	0.12	0.86	0.57	0.15	0.43	0.08
2	Lime	0.3	0.5	<0.01	0.32	0.13	0.69	0.25	0.32	0.1
2	Tillage	0.21	0.13	0.04	0.48	0.22	0.26	0.09	0.55	0.87
2	Starter	0.82	0.33	0.16	0.24	0.24	0.19	0.11	0.37	0.69
2	L*S	0.25	0.18	0.62	0.71	0.76	0.13	0.68	0.18	0.51
2	L*T	0.01	0.29	0.06	0.21	0.75	0.27	0.72	0.57	0.47
2	S*T	0.69	0.15	0.39	0.87	0.91	0.04	0.76	0.67	0.59
2	L*S*T	0.43	0.19	0.4	0.22	0.59	0.04	0.02	0.12	0.04
3	Lime	0.14	0.53	0.02	0.87	0.36	0.48	0.33	0.06	0.44
3	Tillage	0.25	0.38	0.6	0.55	0.41	0.06	0.43	0.81	0.21
3	Starter	0.16	0.04	0.04	0.06	0.01	0.1	0.06	0.02	0.04
3	L*S	0.85	0.66	0.46	0.38	0.23	0.9	0.78	0.64	0.59
3	L*T	0.15	0.1	0.16	0.78	0.6	0.88	0.5	0.34	0.49
3	S*T	0.64	0.2	0.88	0.71	0.82	0.02	0.21	0.71	0.75
3	L*S*T	0.46	0.27	0.85	0.05	0.66	0.16	0.43	0.25	0.09
4	Lime	0.11	0.51	0.45	0.79	0.83	0.26	0.36	0.06	0.8
4	Tillage	0.18	0.53	0.44	0.29	0.3	0.67	0.25	0.88	0.47
4	Starter	0.71	0.9	0.39	0.05	0.43	1	0.83	0.27	0.17
4	L*S	0.15	0.4	0.72	0.07	0.63	0.27	0.16	0.99	0.82
4	L*T	0.92	0.97	0.29	0.28	0.49	0.32	0.31	0.27	0.83
4	S*T	0.96	0.09	0.5	0.39	0.91	0.25	0.58	0.96	0.62
4	L*S*T	0.89	0.62	0.31	0.17	0.05	0.44	0.11	0.7	0.6

Table 5. Soybean (1998) and corn (1999) yield from lime and starter treatments with tillage and no tillage at three sites in Ontario

Tillage	Lime	1998			1999		
		None	Starter	Micro	None	Starter	Micro
		Melbourne, t/ha					
No tillage	None	1.8±0.1	1.8±0.3	1.6±0.3	7.5±0.5	7.3±0.4	8.1±1.1
	Lime	2.4±0.3	2.3±0.1	1.9±0.3	8.5±0.6	8.1±0.9	8.3±0.5
	Pellets	2.3±0.3	2.0±0.1	1.8±0.3	8.1±0.6	8.7±0.5	6.9±0.6
Tilled	None	1.8±0.3	1.9±0.1	2.0±0.2	9.1±0.7	10.1±1.0	9.0±0.9
	Lime	2.1±0.4	2.3±0.1	2.1±0.1	8.9±0.8	10.1±1.1	9.9±0.8
	Pellets	2.2±0.3	2.1±0.2	1.8±0.2	8.4±0.8	8.1±1.3	9.9±1.0
		Thamesville, t/ha					
No tillage	None	2.4±0.2	2.4±0.3	2.3±0.2	5.6±0.7	7.7±0.8	7.3±1.2
	Lime	2.6±0.2	2.6±0.2	2.5±0.2	7.0±0.7	6.9±0.7	7.1±0.8
	Pellets	2.3±0.3	2.6±0.1	2.6±0.2	6.6±1.1	7.8±1.3	7.3±0.6
Tilled	None	2.5±0.1	2.7±0.2	2.3±0.2	6.5±1.1	5.6±0.6	4.8±0.7
	Lime	2.5±0.2	2.5±0.3	2.4±0.2	5.4±1.3	5.2±1.0	6.5±0.9
	Pellets	2.6±0.1	2.8±0.2	2.6±0.3	5.9±0.4	7.4±0.7	7.2±1.1
		Woodslee, t/ha					
No tillage	None	1.9±0.3	2.2±0.3	2.2±0.4	3.0±1.0	4.6±1.2	4.2±0.7
	Lime	1.3±0.3	2.0±0.4	1.8±0.3	2.7±0.9	3.6±1.0	3.3±1.0
	Pellets	1.4±0.1	2.2±0.3	2.0±0.4	2.6±0.5	4.0±0.9	3.9±0.4
Tilled	None	1.6±0.3	2.3±0.3	2.4±0.4	3.6±0.2	4.6±1.2	5.4±1.0
	Lime	1.5±0.3	1.6±0.2	2.2±0.3	2.3±0.2	3.2±0.8	3.8±0.6
	Pellets	1.7±0.3	2.0±0.4	2.1±0.3	3.9±0.8	4.7±1.3	4.7±1.1

Table 6. Probability of greater F statistics for tillage (T), lime (L) and starter (S) effects on grain yield at three sites in Ontario

Attribute	Melbourne		Thamesville		Woodslee	
	1998	1999	1998	1999	1998	1999
Lime(L)	0.01	0.32	0.32	0.28	0.06	0.05
Tillage(T)	0.58	<0.01	0.66	0.25	0.80	0.44
Starter(S)	0.15	0.63	0.27	0.11	<0.01	<0.01
LxS	0.71	1.00	0.66	0.20	0.93	0.98
LxT	0.57	0.05	0.47	0.59	0.96	0.67
SxT	0.41	0.70	0.78	0.66	0.17	0.46
LxSxT	0.96	0.46	0.88	0.43	0.17	0.89

Table 7. Probability of greater F statistic for soil nutrients in the 0 to 15 cm depth at Thamesville

Attribute	Year	P	K	Mg	Mn	Zn	Ca	OM
		Probability of greater F						
Lime(L)	1998	0.85	0.90	0.46	0.59	0.86	0.91	0.41
Tillage(T)		0.74	0.53	0.52	0.19	0.26	0.47	0.55
Starter(S)		0.36	0.51	0.27	0.13	0.37	0.08	0.32
L*S		0.20	0.55	0.49	0.94	0.77	0.33	0.84
L*T		0.81	0.44	0.32	0.30	0.39	0.24	0.91
S*T		0.17	0.36	0.37	0.59	0.11	0.58	0.54
L*S*T		<.01	0.56	0.15	0.43	0.35	0.14	0.49

Table 8. Concentration of phosphorus in soil at Thamesville, 1998

Year	Lime	Starter	Tillage	No tillage
			P, ppm	
1998	None	No starter	83±5	96±10
		Starter	95±7	103±10
		Micronutrients	97±0	80±7
	Lime	No starter	83±6	99±19
		Starter	96±6	92±10
		Micronutrients	97±7	81±12
	Pellets	No starter	91±4	87±9
		Starter	95±10	87±8
		Micronutrients	88±4	112±4

Table 9. Nutrient composition in plant tissue (soybean, 1998; corn, 1999) at three sites, averaged over all treatments.

Year	N,%	P, %	K,%	Ca,%	Mg,%	Fe, ppm	Mn,ppm	Cu,ppm	Zn,ppm	S, %	Na, %	B, ppm	Al, ppm
	Melbourne												
1998	5.0	.33	2.0	.59	.20	119	155	6.8	101	nd	nd	28	nd
1999	3.7	.35	2.1	.38	.18	nd	145	10.6	77	nd	nd	99	5.8
	Thamesville												
1998	6.1	.36	1.7	.73	.32	104	69	7.9	46	.18	0.2	28	48
1999	nd	0.27	1.68	0.32	0.24	66	41	5.7	33	0.12	0.03	6	24
	Woodslee												
1998	5.9	.32	1.4	1.25	.56	115	67	12.1	54	nd	nd	nd	nd
1999	2.8	.28	1.5	.47	.47	88	61	10.6	47	nd	0.01	10	nd
	Critical level												
Soybean	4.0	0.15	1.2	3.0	0.10		14	4	12			20	
Corn	2.5	0.15	1.2	1.5	0.10		15	2	14	0.14		2	

nd=not determined

Table 10. Probability of greater F statistic for nutrients in soybean (1998) and corn (1999) at Thamesville

Attribute	Year	N	S	P	K	Mg	Ca	Na	B	Zn	Mn	Fe	Cu	Al
		Probability of greater F												
Lime(L)	1998	0.90	0.30	13.00	0.81	0.46	0.46	0.88	0.69	0.93	0.36	0.28	0.60	0.48
Tillage(T)		0.97	0.61	0.74	0.45	0.30	0.03	0.22	0.41	0.58	0.87	0.50	0.91	0.09
Starter(S)		0.53	0.39	0.51	0.02	0.77	0.12	<.01	0.32	0.26	0.60	0.05	0.05	0.39
L*S		0.67	0.56	0.70	0.16	0.47	0.94	0.80	0.95	0.42	0.83	0.34	0.89	0.61
L*T		0.31	0.14	0.04	0.42	0.22	0.36	0.38	0.30	0.73	0.63	0.47	0.11	0.24
S*T		0.68	0.06	0.18	0.30	0.26	<.01	0.11	0.04	0.19	0.92	0.06	0.51	0.32
L*S*T		0.45	0.23	0.37	0.58	0.68	0.42	0.05	0.25	0.48	0.38	0.41	0.64	0.68
Lime	1999	nd	0.35	0.70	0.69	0.56	0.27	0.48	0.90	0.91	0.17	0.67	0.61	0.48
Cultivation		nd	0.50	0.86	0.14	0.04	0.42	0.72	0.53	0.18	0.64	0.70	0.11	0.62
Starter		nd	0.38	0.03	<0.01	<0.01	<0.01	0.85	0.51	0.42	0.16	0.08	0.02	0.33
L*S		nd	0.51	0.35	0.69	0.79	0.84	0.27	0.32	0.74	0.57	0.67	0.63	0.48
L*T		nd	0.74	0.24	0.23	0.96	0.85	0.75	0.80	0.78	0.31	0.18	0.54	0.39
S*T		nd	0.43	0.90	0.99	0.11	0.14	0.31	0.24	0.03	0.48	0.04	0.83	0.26
L*S*T		nd	0.63	0.13	0.74	0.39	0.56	0.50	0.98	0.38	0.35	0.28	0.42	0.36

Table 11. Probability of greater F statistic for soil pH at four depths (see Table 4 for depths) and nine sampling dates (see Table 1 for dates) at Woodslee

Depth	Attribute	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
		Probability of greater F									
1	Lime(L)	0.96	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	0.01
1	Tillage(T)	0.91	0.94	0.76	0.17	0.16	0.46	0.5	0.84	0.53	0.01
1	Starter(S)	0.34	0.24	0.74	0.63	0.36	0.01	0.43	0.22	0.41	0.35
1	L*S	0.42	0.93	0.74	0.02	0.35	0.06	0.16	0.61	0.88	0.21
1	L*T	0.11	0.41	0.57	0.27	0.51	0.92	0.22	0.67	0.65	0.97
1	S*T	0.97	0.16	0.43	0.33	0.62	0.89	0.55	0.85	0.62	0.11
1	L*S*T	0.91	0.63	0.62	0.49	0.91	0.93	0.99	0.87	0.8	0.38
2	Lime	0.99	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	0.19	0.02	<0.01
2	Tillage	0.89	0.73	0.29	0.68	0.49	0.43	0.25	0.47	0.34	0.03
2	Starter	0.5	0.14	0.14	0.1	0.04	0.05	0.11	0.38	1	0.01
2	L*S	0.3	0.09	0.27	0.27	0.67	0.13	0.51	0.99	0.9	0.76
2	L*T	0.75	0.9	0.46	0.06	0.06	0.01	0.1	0.56	0.35	0.11
2	S*T	0.86	0.83	0.14	0.68	0.8	0.91	0.11	0.99	0.82	0.17
2	L*S*T	0.94	0.71	0.3	0.2	0.66	0.04	0.26	0.66	0.28	0.27
3	Lime	0.8	0.34	0.08	0.1	0.11	0.2	0.02	0.2	0.02	0.05
3	Tillage	0.93	0.66	0.07	0.6	0.37	0.76	0.11	0.84	0.35	0.29
3	Starter	0.8	0.94	0.32	0.53	0.5	0.88	0.46	0.99	0.33	0.44
3	L*S	0.75	0.35	0.11	0.61	0.78	0.63	0.59	0.05	0.54	0.48
3	L*T	0.23	0.82	0.71	0.08	0.9	0.23	0.14	0.24	0.65	0.82
3	S*T	0.8	0.98	0.67	0.4	0.11	0.5	0.91	0.81	0.89	0.18
3	L*S*T	0.08	0.78	0.75	0.88	0.37	0.34	0.1	0.94	0.08	0.16
4	Lime	0.29	0.11	0.06	0.07	0.12	0.77	0.41	0.79	0.07	0.76
4	Tillage	0.88	0.89	0.63	0.5	0.86	0.9	0.84	0.36	0.68	62
4	Starter	0.92	0.52	0.87	0.92	0.95	0.81	0.85	0.3	0.67	0.76
4	L*S	0.42	0.85	0.71	0.53	0.31	0.13	1	0.5	0.7	0.79
4	L*T	0.9	0.91	0.97	0.17	0.88	0.17	0.15	0.25	0.3	0.22
4	S*T	0.81	0.76	0.74	0.53	0.95	0.42	0.44	0.37	0.79	0.89
4	L*S*T	0.59	0.5	0.52	0.75	0.69	0.71	0.87	0.95	0.43	0.67

Table 12. Probability of greater F statistic for soil nutrients in the 0 to 15 cm depth at Woodslee

Attribute	Year	OM	P	K	Mg	Ca	CEC	Mn	Zn	Fe	Cu
		Probability of greater F									
Lime(L)	1998	0.31	0.87	0.23	0.18	0.43	0.59	0.54	0.73	0.34	0.51
Tillage(T)		0.37	0.74	0.04	0.47	0.37	0.35	0.03	0.11	0.28	0.21
Starter(S)		0.33	0.36	0.37	0.69	0.40	0.39	0.42	0.23	0.87	0.17
L*S		0.13	0.19	0.67	0.74	0.61	0.05	0.41	0.11	<.01	0.06
L*T		0.63	0.48	0.71	0.23	0.06	0.99	0.88	0.62	0.81	0.59
S*T		0.28	0.20	0.61	0.30	0.83	0.27	0.21	0.39	0.45	0.29
L*S*T		0.51	0.37	0.24	0.73	0.97	0.64	0.49	0.65	0.76	0.94
Lime	1998	0.28	0.35	0.76	0.14	0.41	0.26	0.35	0.06	0.06	0.30
Tillage		0.27	0.39	0.01	0.49	0.50	0.46	0.05	0.07	0.42	0.11
Starter		0.61	0.28	0.19	0.44	0.66	0.71	0.26	0.53	0.58	0.34
L*S		0.61	0.06	0.23	0.13	0.06	0.10	0.32	0.06	0.05	0.40
L*T		0.93	0.30	0.13	0.14	0.16	0.10	0.34	0.84	0.62	0.68
S*T		0.93	0.39	0.53	0.20	0.93	0.76	0.63	0.67	0.38	0.57
L*S*T		0.72	0.77	0.84	0.84	0.61	0.65	0.19	0.84	0.79	0.85
Lime	1999	0.96	0.12	0.66	<.01	0.04		0.19	0.25		
Tillage		0.37	0.10	0.17	0.66	0.61		0.74	0.02		
Starter		0.21	0.33	<.01	0.64	0.64		0.48	0.95		
L*S		0.52	0.58	0.43	0.45	0.14		0.33	0.96		
L*T		0.84	0.91	0.37	0.15	0.64		0.36	0.11		
S*T		0.44	0.56	0.35	0.12	0.42		0.82	0.18		
L*S*T		0.60	0.95	0.49	0.75	0.28		0.83	0.93		

Table 13. Probability of greater F statistic for soil nutrients in the 0 to 15 cm depth at Woodslee

Attribute	Year	OM	P	K	Mg	Ca	CEC	Mn	Zn	Fe	Cu
		Probability of greater F									
Lime(L)	1998	0.31	0.87	0.23	0.18	0.43	0.59	0.54	0.73	0.34	0.51
Tillage(T)		0.37	0.74	0.04	0.47	0.37	0.35	0.03	0.11	0.28	0.21
Starter(S)		0.33	0.36	0.37	0.69	0.40	0.39	0.42	0.23	0.87	0.17
L*S		0.13	0.19	0.67	0.74	0.61	0.05	0.41	0.11	<.01	0.06
L*T		0.63	0.48	0.71	0.23	0.06	0.99	0.88	0.62	0.81	0.59
S*T		0.28	0.20	0.61	0.30	0.83	0.27	0.21	0.39	0.45	0.29
L*S*T		0.51	0.37	0.24	0.73	0.97	0.64	0.49	0.65	0.76	0.94
Lime	1998	0.28	0.35	0.76	0.14	0.41	0.26	0.35	0.06	0.06	0.30
Tillage		0.27	0.39	0.01	0.49	0.50	0.46	0.05	0.07	0.42	0.11
Starter		0.61	0.28	0.19	0.44	0.66	0.71	0.26	0.53	0.58	0.34
L*S		0.61	0.06	0.23	0.13	0.06	0.10	0.32	0.06	0.05	0.40
L*T		0.93	0.30	0.13	0.14	0.16	0.10	0.34	0.84	0.62	0.68
S*T		0.93	0.39	0.53	0.20	0.93	0.76	0.63	0.67	0.38	0.57
L*S*T		0.72	0.77	0.84	0.84	0.61	0.65	0.19	0.84	0.79	0.85
Lime	1999	0.96	0.12	0.66	<.01	0.04		0.19	0.25		
Tillage		0.37	0.10	0.17	0.66	0.61		0.74	0.02		
Starter		0.21	0.33	<.01	0.64	0.64		0.48	0.95		
L*S		0.52	0.58	0.43	0.45	0.14		0.33	0.96		
L*T		0.84	0.91	0.37	0.15	0.64		0.36	0.11		
S*T		0.44	0.56	0.35	0.12	0.42		0.82	0.18		
L*S*T		0.60	0.95	0.49	0.75	0.28		0.83	0.93		

Table 14. Probability of greater F statistic for soil pH (see Table 4 for depths) at four depths and ten sampling dates (see Table 1 for dates) at Melbourne

Depth	Attribute	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
		Probability of greater F									
1	Lime(L)	0.71	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
1	Tillage(T)	0.19	0.07	0.05	0.71	0.52	0.63	0.81	0.97	0.8	0.67
1	Starter(S)	0.76	0.42	0.54	0.97	0.98	0.3	0.88	0.34	0.14	0.06
1	L*S	0.09	0.48	0.05	0.48	0.21	0.33	0.72	0.53	0.76	0.28
1	L*T	0.92	0.89	0.34	0.55	0.15	0.24	0.04	0.6	0.08	0.45
1	S*T	0.95	0.99	0.64	0.83	0.69	0.9	0.78	0.99	0.68	0.78
1	L*S*T	0.86	0.99	0.94	0.94	0.62	0.9	0.84	0.61	0.48	0.77
2	Lime	0.49	<0.01	0.11	<0.01	0.04	<0.01	<0.01	0.03	<0.01	<0.01
2	Tillage	0.21	0.65	0.83	0.16	0.31	0.26	0.9	0.72	0.18	0.68
2	Starter	0.55	0.21	0.24	0.09	0.08	0.05	0.04	0.07	0.03	0.37
2	L*S	0.52	0.72	0.6	0.58	0.53	0.76	0.42	0.51	0.7	0.72
2	L*T	0.93	0.45	0.27	0.46	0.07	0.07	0.32	0.07	0.05	0.91
2	S*T	0.93	0.9	0.84	0.98	0.46	0.9	0.84	1	0.87	0.86
2	L*S*T	0.98	0.93	0.91	0.88	0.41	0.94	0.77	0.57	0.66	0.7
3	Lime	0.48	0.04	0.1	0.11	0.03	0.25	0.16	0.98	0.07	0.01
3	Tillage	0.18	0.61	0.48	0.13	0.06	0.1	0.04	0.05	0.56	0.21
3	Starter	0.58	0.62	0.49	0.25	0.53	0.18	0.35	0.02	0.03	0.09
3	L*S	0.17	0.32	0.89	0.52	0.13	0.59	0.61	0.03	0.29	0.19
3	L*T	0.8	0.73	0.92	0.86	0.8	0.6	0.74	0.24	0.45	0.35
3	S*T	0.9	0.92	0.84	0.77	0.98	0.81	0.92	0.99	0.93	0.87
3	L*S*T	0.84	0.96	0.95	0.94	0.92	0.9	0.66	0.99	0.82	0.94
4	Lime	0.27	0.64	0.54	0.52	0.25	0.47	0.56	0.79	0.4	0.09
4	Tillage	0.09	0.07	0.74	0.05	0.29	0.09	0.05	0.72	0.01	0.07
4	Starter	0.44	0.61	0.38	0.52	0.53	0.59	0.38	0.19	0.21	0.26
4	L*S	0.22	0.51	0.62	0.47	0.16	0.47	0.36	0.29	0.21	0.93
4	L*T	0.72	0.74	0.58	0.84	0.88	0.98	0.98	0.67	0.97	0.94
4	S*T	0.97	0.94	0.96	0.93	0.91	0.49	0.95	0.88	0.95	0.85
4	L*S*T	0.94	0.91	0.94	0.84	0.92	0.61	0.94	0.96	0.95	0.53

Table 15. Probability of greater F statistic for soil nutrients in the 0 to 15 cm depth at Melbourne

Attribute	Year	OM	P	K	Mg	Ca	Zn	Mn	CEC
		Probability of greater F							
Lime(L)	1998	0.96	0.53	0.90	0.43	0.61	0.55	0.89	0.62
Tillage(T)		0.11	0.74	0.33	0.47	0.49	0.05	0.43	0.46
Starter(S)		0.94	0.85	0.48	0.26	0.13	0.08	0.05	0.11
L*S		0.80	0.50	0.30	0.27	0.35	0.04	0.25	0.43
L*T		0.02	0.06	0.49	0.80	0.94	0.13	0.61	0.92
S*T		0.45	0.84	0.44	0.83	0.87	1.00	0.89	0.75
L*S*T		0.31	0.84	0.64	0.73	0.66	0.90	0.65	0.84
Lime	1998	0.27	0.84	0.66	< 01	0.04	0.40	0.28	0.14
Tillage		0.49	0.21	0.01	0.73	0.53	0.12	0.58	0.41
Starter		0.88	0.24	0.15	0.27	0.08	0.03	0.01	0.15
L*S		0.91	0.07	0.18	1.00	0.74	0.11	0.47	0.75
L*T		0.26	0.18	0.62	0.99	0.90	0.02	0.76	0.91
S*T		0.22	0.62	0.94	0.93	0.98	0.52	0.92	0.94
L*S*T		0.16	0.67	0.92	0.47	0.40	0.92	0.93	0.41
Lime	1999	0.30	0.48	0.60	< 01	< 01	0.11	0.06	
Tillage		0.53	0.47	0.32	0.13	0.31	0.14	0.20	
Starter		0.92	0.90	0.18	0.55	0.58	0.08	0.20	
L*S		0.40	0.34	0.84	0.94	0.84	0.80	0.77	
L*T		0.21	0.62	0.12	0.06	0.61	0.46	0.19	
S*T		0.52	0.78	0.08	0.67	0.57	0.93	0.99	
L*S*T		0.41	0.77	0.27	0.52	0.67	0.58	0.73	

Table 16. Probability of greater F statistic for nutrients in soybean(1998) and corn(1999) at Melbourne

Attribute	Year	N	P	K	Mg	Ca	Zn	Mn	Cu	B	Fe
		Probability of greater F									
Lime(L)	1998	0.75	0.80	0.93	0.05	0.64	0.40	0.04	0.10	0.26	0.75
Tillage(T)		0.86	0.32	0.85	0.76	0.70	0.15	0.21	0.42	0.22	0.59
Starter(S)		0.90	0.25	0.33	0.45	0.02	0.68	0.36	0.94	0.10	0.60
L*S		0.99	0.24	0.26	0.17	0.65	0.05	0.99	0.26	0.89	0.81
L*T		0.09	0.50	0.03	0.28	0.44	0.20	0.93	0.07	0.39	0.77
S*T		0.92	0.51	0.46	0.45	0.99	0.85	0.07	0.42	0.58	0.97
L*S*T		0.57	0.59	0.59	0.10	0.26	0.88	0.58	0.94	0.75	0.92
Attribute	Year	N	P	K	Mg	Ca	Zn	Mn	Cu	B	Al
Lime	1999	0.10	0.69	0.81	<.01	0.29	0.14	0.01	0.12	0.20	0.31
Tillage		0.46	0.36	0.72	0.02	0.08	0.23	0.07	0.17	0.73	0.41
Starter		0.19	0.26	<.01	0.06	0.29	0.34	0.51	0.58	0.69	0.25
L*S		0.77	0.78	0.90	0.50	0.36	0.44	0.76	0.61	0.70	0.40
L*T		0.21	0.95	0.21	0.23	0.52	0.03	0.50	0.04	0.48	0.89
S*T		0.24	0.79	0.51	0.79	0.73	0.88	0.54	0.46	0.22	0.71
L*S*T		0.83	0.38	0.68	0.90	0.71	0.75	0.59	0.83	0.40	0.26

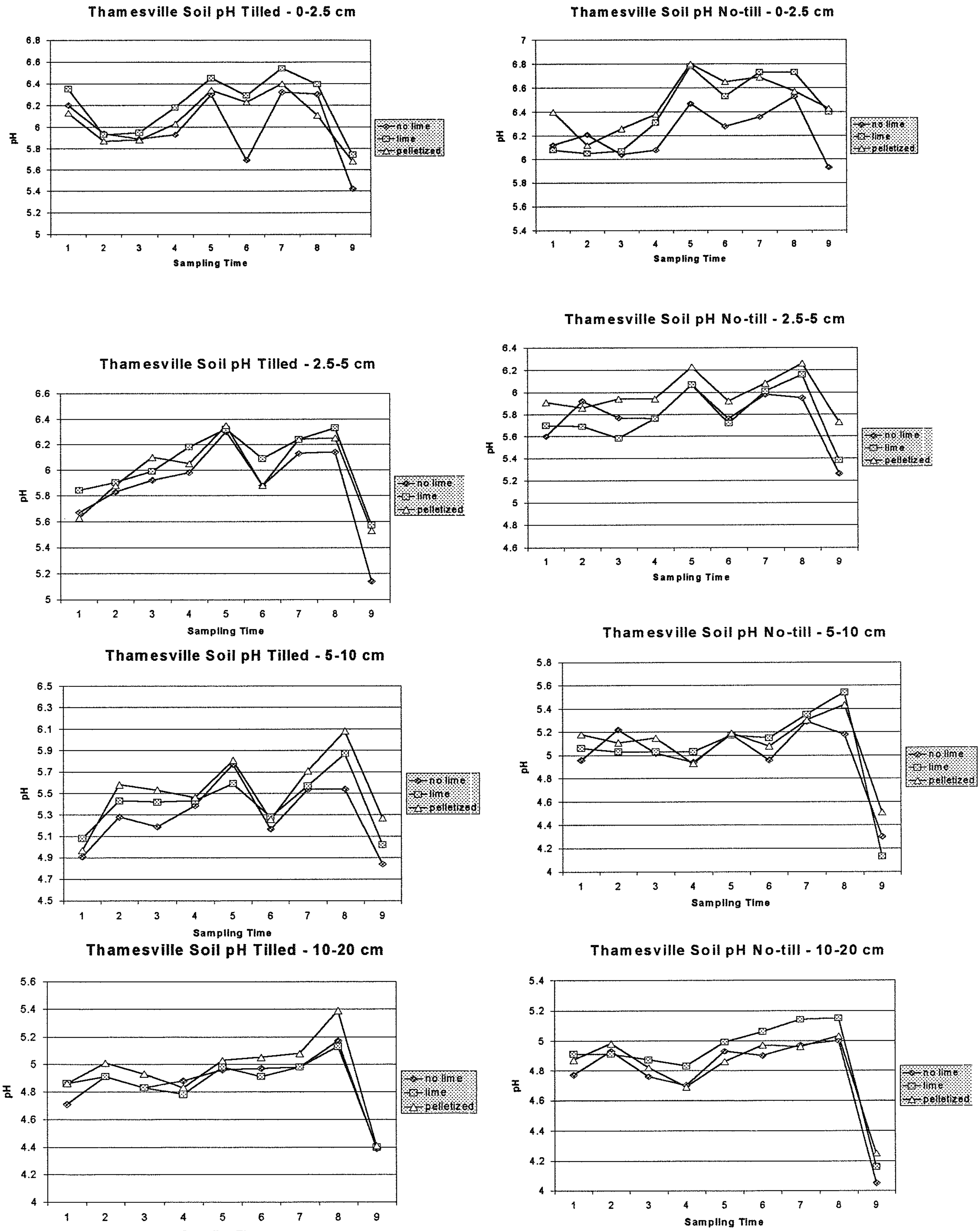
LIST OF FIGURES

Figure 1. Effect of lime and tillage on soil pH at four depths and nine sampling dates at Thamesville. See table 2 for sampling dates corresponding to sample number.

Figure 2. Effect of lime and tillage on soil pH at four depths and ten sampling dates at Woodslee. See table 2 for sampling dates corresponding to sample number.

Figure 3. Effect of lime and tillage on soil pH at four depths and ten sampling dates at Melbourne. See table 2 for sampling dates corresponding to sample number.

igure 1. Effect of lime and tillage on soil pH at four depths and nine sampling dates at Thamesville. See table 2 for sampling dates corresponding to sample number.



Thamesville Soil pH Tilled - 0-2.5 cm

Thamesville Soil pH No-till - 0-2.5 cm

Thamesville Soil pH Tilled - 2.5-5 cm

Thamesville Soil pH No-till - 2.5-5 cm

Thamesville Soil pH Tilled - 5-10 cm

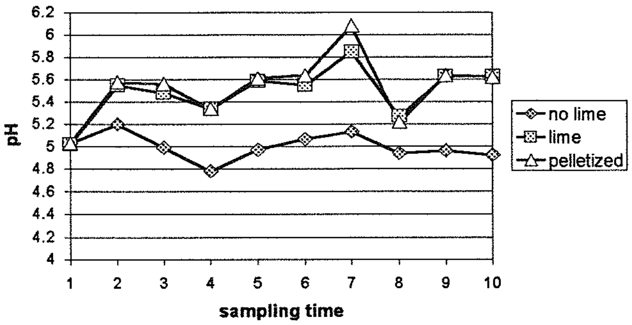
Thamesville Soil pH No-till - 5-10 cm

Thamesville Soil pH Tilled - 10-20 cm

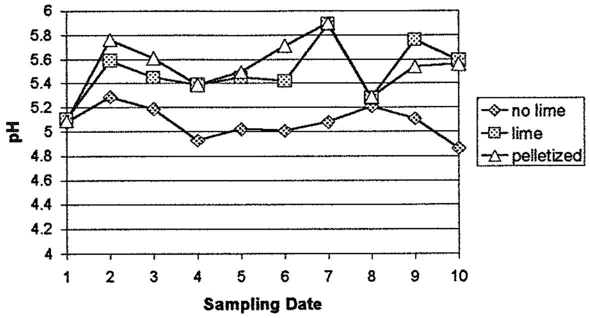
Thamesville Soil pH No-till - 10-20 cm

Figure 2. Effect of lime and tillage on soil pH at four depths and ten sampling dates at Woodslee. See table 2 for sampling dates corresponding to sample number.

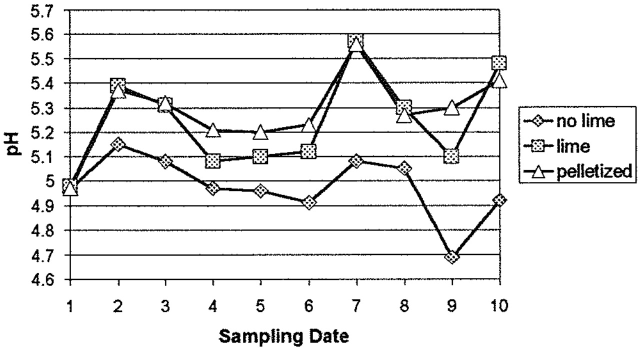
Woodslee Soil pH Tilled - 0-2.5 cm



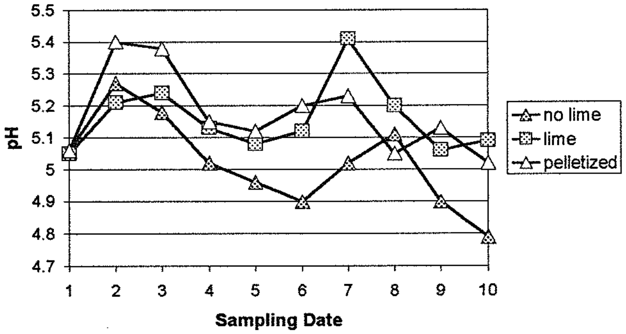
Woodslee Soil pH No-till - 0-2.5 cm



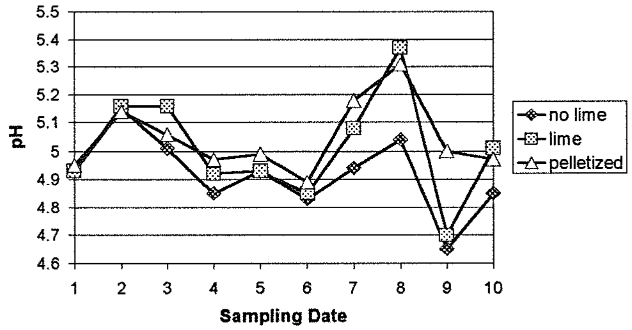
Woodslee Soil pH Tilled - 2.5-5 cm



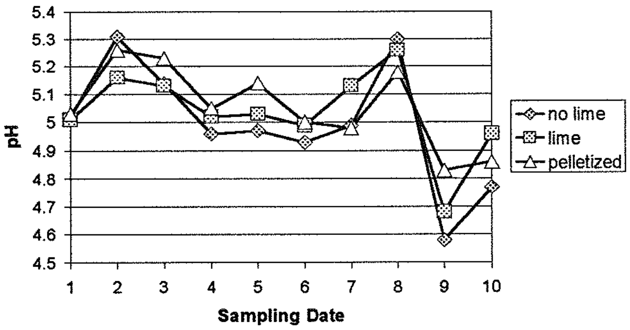
Woodslee Soil pH No-till - 2.5-5 cm



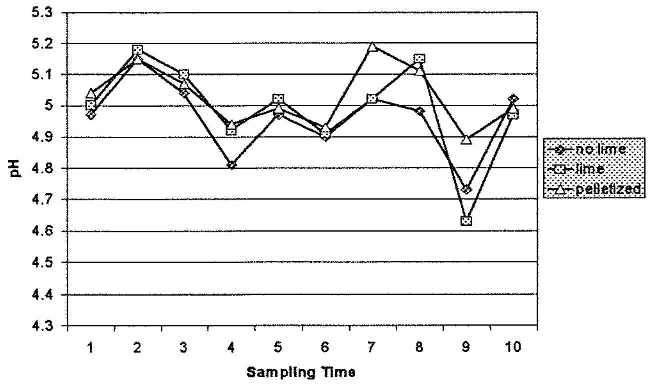
Woodslee Soil pH Tilled - 5-10 cm



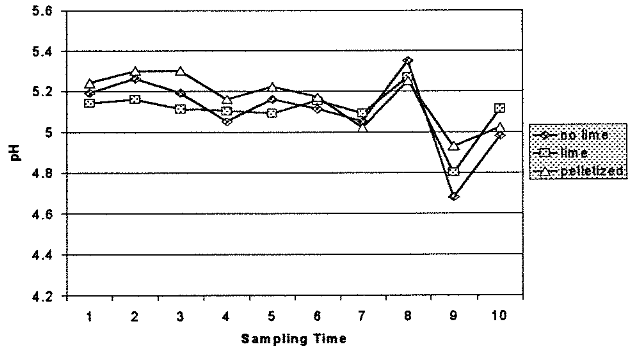
Woodslee Soil pH No-till - 5-10 cm



Woodslee Soil pH Tilled - 10-20 cm



Woodslee Soil pH No-till - 10-20 cm



igure 3. Effect of lime and tillage on soil pH at four depths and ten sampling dates at Melbourne. See table 2 for sampling dates corresponding to sample number.