# Nutrient Availability to Corn From Dairy Manures and Fertilizer in a Calcareous Soil

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**Abstract:** The expansion of the dairy industry in southern Idaho has led to increased application of manures to meet crop nutrient demands that can alter the uptake pattern of both macronutrients and micronutrients. A greenhouse study was conducted to determine the effects of dairy manure, composted dairy manure, and fertilizer (monoammonium phosphate) application on soil test phosphorus (P), microbial activity, and nutrient uptake by silage corn (*Zea mays*). Two Portneuf soils, having either a low or high soil test P concentration, were amended with the three treatments at four application rates (25, 50, 100, and 200 mg P $kg^{-1}$) with four replications of each treatment in a randomized complete design. Treatments were incubated for 2 weeks, then planted with corn grown for approximately 3 weeks. Soil samples were analyzed before planting, whereas plant samples were analyzed at the end of the growing period. Increases in Olsen P from P additions were greatest in the monoammonium phosphate and least in the manure-treated soils. Plant dry matter production and tissue P concentration did not differ with treatment. Tissue K increased with manure and compost addition, whereas tissue Ca decreased; there was also a decrease in tissue Mg with compost application. Tissue Zn increased with manure applications, whereas tissue Mn decreased with manure and compost application on the low-P soil. It is important to consider plant nutrient interactions when applying manure and compost to forage crops as imbalances in K, Ca, and Mg can have a negative impact on animal health.

**Key words:** Dairy, micronutrients, manure, compost, fertilizer, microbial activity.

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Expansion of the dairy industry in southern Idaho has led to an increase in applications of dairy manures and compost to meet crop nutritional requirements. One of the benefits of fertilizing with compost or manure is the provision of secondary nutrients other than nitrogen (N), phosphorus (P), and potassium (K) commonly supplied by commercial fertilizers. This may result in higher tissue macronutrient and micronutrient contents in crops amended with manure and compost compared with those fertilized with traditional inorganic fertilizers. For example, Raj and Gupta (1986) reported that application of manure increased both zinc (Zn) tissue concentration and plant uptake in wheat. Warman (1986) reported higher copper (Cu) contents in timothy hay that had received chicken manure compared with an NPK-fertilizer treatment. Conversely, manure and compost additions have also been shown to decrease the uptake of some nutrients. Warman and Cooper (2000b) found that additions of compost resulted in decreased magnesium (Mg) uptake as well as lower tissue concentrations of manganese (Mn) compared with NPK-fertilizer treatments, whereas Parsons et al. (2007) found decreased calcium (Ca) uptake in manured soils compared with control and NPK-fertilizer treatments.

There has been a great deal of research related to N, P, and K mineralization after manure application in various climates and soil conditions (Bar-Tal et al., 2004; Eghball et al., 2002; Irshad et al., 2002; Whalen et al., 2001; Meek et al., 1982). However, there has not been much focus on the effects of manure application on the uptake of other macronutrients such as Ca, Mg, and micronutrients such as iron (Fe), Mn, and Zn. The application of manure to meet crop N requirements, which has been the common practice in the region, can apply large amounts of P, Ca, and K, as well as other trace minerals and some heavy metals, which can affect crop growth and forage quality.

For example, high K application rates with manures on grasses have been shown to decrease Ca uptake and increase the tetany potential of those grasses (Cherney et al., 2002). In addition, accumulation of K in forages is a concern from an animal health perspective as high levels of K can lead to milk fever in dairy cattle (Tyler and Ensminger, 2006). The overapplication of P and P accumulation in soils has the potential to create deficiencies and toxicities of other nutrients as well. For example, several research studies have shown that Zn deficiencies can be induced with excessively high concentrations of P fertilizer in the soil (Singh et al., 1988; Cakmak and Marschner, 1986; Singh et al., 1986). Manure additions also tend to have a liming effect in most soils as large amounts of Ca and Mg are added with the manures (Eghball et al., 2004; Mokolobate and Haynes, 2002). This increase in pH can affect mineral uptake as the solubility and plant availability of all plant nutrients are sensitive to changes in pH.

Land application of manure applies not only to nutrients but also large amounts of organic material that can affect mineral solubility and plant availability. In some instances, the addition of organic matter has been found to enhance nutrient availability such as P and other trace minerals. For example, it has been reported that the addition of organic material enhanced P solubility primarily through coating of reactive surfaces and inhibition of Ca-P precipitation (Inskeep and Silvertooth, 1988; Leytem and Westermann, 2003). This same phenomenon is found with metals such as Zn, which may become more available as organic matter in the manure chelates these metals, improving their solubility and plant uptake (García-Mina et al., 2004). Conversely, it has also been found that chelation of some metals by organic matter makes trace minerals less available to plants (Laurie and Manthey, 1994).

The addition of organic matter stimulates the activity of microorganisms in the soil, which can temporarily decrease the availability of some nutrients as they are incorporated into microbial tissues. Conversely, microbial activity can enhance the solubility of some minerals as they are released during breakdown of organic materials in the soil (Coyne, 1999). Therefore, it is important that we understand the impact of manure applications on nutrient availability and crop uptake in regions where

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heavy manure applications are common. The objective of this study was to determine the effect of dairy manure, composted dairy manure, and commercial fertilizer on changes in soil test P and plant tissue K, Ca, Fe, Mg, Mn, P, and Zn concentrations and the possible role of microbial activity in these relationships.

## MATERIALS AND METHODS

### Soil Collection and Characterization

The soils used in this study were Portneuf silt loams (coarse-silty, mixed superactive, mesic Durinodic Xeric Haplocalcids) from the 0- to 20-cm depth located at the Northwest Irrigation and Soils Research Laboratory in Kimberly, Idaho (Table 1). The soils were chosen to represent a soil that is deficient in P (for optimum crop production, low P) as well as a soil typical of those receiving manure applications having a higher Olsen P (high P). After collection, the bulk soil samples were air dried, sieved through a 7-mm screen, and analyzed before use in the greenhouse studies. Particle size was determined by the hydrometer method (Gee and Bauder, 1986), calcium carbonate equivalent (CCE) by the titrimetric method of Allison and Moodie (1965), sodium bicarbonate-extractable P (Olsen P: Olsen et al., 1954; Kuo, 1996), and total carbon (TC) by combustion of a 50-mg sample in a FlashEA1112 (CE Elantech, Lakewood, NJ), and pH was measured in a 1:1 (wt/vol) mixture of soil and deionized water using a combination electrode. Olsen P concentrations were determined by the ascorbic acid method (Kuo, 1996).

### Manure Collection and Characterization

There were four treatments including fertilizer (monoammonium phosphate [MAP], 11-52-0), fresh manure collected from an open-lot dairy, composted manure from the same open-lot dairy, and a control that received no amendments (Table 2). Manure samples were dried in a forced air oven (60°C) and ground for analysis and use in the greenhouse studies. Analysis of the manures were as follows: (i) total elements (Ca, Fe, K, Mg, Mn, P, Zn) by microwave-assisted digestion of a 0.5-g dried sample with 8 mL of concentrated $HNO_3$ and 2 mL of 30% $H_2O_2$ and quantified by inductively coupled plasma optical emission spectroscopy (PerkinElmer Optima 4300 DV, Wellesley, MA; US Environmental Protection Agency, 1996 [method 3052]) and (ii) total N and carbon (C) were determined by combustion of a 50-mg sample in a FlashEA1112 (CE Elantech).

### Greenhouse Studies

Greenhouse studies with the individual soils were conducted in two sequential experiments because of space limitations. For each experiment, there were two mixtures prepared:

**TABLE 1.** Selected Chemical and Physical Properties of the Calcareous Soils (From Southern Idaho) Used to Determine the Influence of Fertilizer, Manure, and Compost Treatments on Nutrient Availability and Plant Nutrient Uptake

| Soil Property | High P | Low P |
|---|---|---|
| Sand, g $kg^{-1}$ | 203 | 166 |
| Silt, g $kg^{-1}$ | 598 | 606 |
| Clay, g $kg^{-1}$ | 199 | 228 |
| TC, g $kg^{-1}$ | 23 | 17 |
| CCE, g $kg^{-1}$ | 27 | 68 |
| pH | 7.5 | 7.9 |
| Olsen P, mg $kg^{-1}$ | 28 | 4 |

**TABLE 2.** Select Chemical Properties of Manure and Compost Used to Determine the Effects of Fertilizer, Manure, and Compost Application on Nutrient Availability and Plant Nutrient Uptake on Calcareous Soils in Southern Idaho

| | Manure | Compost |
|---|---|---|
| P,† g $kg^{-1}$ | 5.4 | 4.1 |
| Ca,† g $kg^{-1}$ | 16.9 | 12.3 |
| Fe,† g $kg^{-1}$ | 1.3 | 9.5 |
| K,† g $kg^{-1}$ | 6.5 | 19.5 |
| Mg,† g $kg^{-1}$ | 6.9 | 7.7 |
| Mn,† g $kg^{-1}$ | 0.20 | 0.22 |
| Zn,† g $kg^{-1}$ | 0.21 | 0.09 |
| C,‡ g $kg^{-1}$ | 395 | 99 |
| N,‡ g $kg^{-1}$ | 21 | 7.4 |
| C:P | 7.4 | 2.4 |
| C:N | 18.8 | 13.4 |

†Total P, Ca, Fe, K, Mg, Mn, and Zn determined by microwave-assisted digestion.

‡Total N and C determined by combustion.

220 g soil + amendment for sampling after 2 weeks' incubation (for soil analysis after treatment application) and 2.5 kg soil + amendment for plant growth studies. Each of the P sources was incorporated (four replicates of each source) by mixing with each soil at four rates: 25, 50, 100, and 200 mg P $kg^{-1}$ to represent a range of P additions around a typical application rate (60 mg $kg^{-1}$) when manures are applied to meet crop N requirements. Urea was added to all treatments at a rate of 150 mg N $kg^{-1}$ to satisfy the N requirements of the plants. After incorporation, amended soils were brought to approximately 80% field capacity using simulated irrigation water (1:1 vol/vol tap and deionized water) and incubated in a completely randomized design in either 4-L closed bottomed pots or 250 mL polyethylene containers in the greenhouse for 2 weeks. Soil-moisture content was maintained by adding water to the containers or to the pots every other day.

After 2 weeks' incubation, soils were removed from the polyethylene containers (250 g) for subsequent analysis, and silage corn (*Zea mays*) was planted into the 2.5-kg soil pots. Greenhouse photoperiod was approximately 14/10 h (day/night) using additional lighting when necessary (368 μmol $s^{-1}$ $m^{-2}$). The average air temperature was 32°C/17°C (day/night) for the high-P soil and 35°C/20°C (day/night) for the low-P soil. After emergence, plants were thinned to six per pot and were grown for 25 days on the high-P soil and 21 days on the low-P soil. Whole plant samples were cut 1 cm above the soil surface, dried, weighed, and ground for analysis.

All soil samples were analyzed without drying as follows: (i) dehydrogenase activity (DHA) and (ii) alkaline phosphomonoesterase activity. The DHA was determined using a modified method of von Mersi and Schinner (1991), where 2-(4-idophenyl)-3-(4-nitrophenyl)-5-phenyltetrazolium chloride (INT) is reduced to iodonitrotetrazolium formazan (INTF). In brief, 0.5 g of soil (dry weight) was placed in a 15-mL glass amber threaded vial and mixed with 0.75 mL of Tris buffer (1 *M*, pH 7) and 1 mL of INT solution (9.9 m*M*). The vials were sealed with screw-top closures and incubated for 2 h at 40°C with vigorous shaking every 20 min. After the incubation period, 0.5 mL of the solution was transferred to 0.65-mL polypropylene tubes and centrifuged at 9300*g* for 1 min. A 200-μL aliquot of supernatant was then dispensed into a 96-well microplate

(Corning Inc., Corning, NY), and absorbance was measured at 450 nm using an ELx808 microplate reader (BioTek Instruments Inc., Winooski, VT). Negative controls were prepared by autoclaving soil for 20 min at 1.23 atm and 121°C. Calibration curve regression coefficients ($r^2$) were 0.98 or greater, and DHA is expressed as μg INTF g dry soil $h^{-1}$.

The phosphatase activity was based on the determination of *p*-nitrophenol released after the incubation of soil with *p*-nitrophenyl phosphate (PNP; Tabatabai and Bremner, 1969; Eivazi and Tabatabai, 1977). A 0.5-g sample of soil (dry weight) was placed in a 15-mL glass amber threaded vial and mixed with 2 mL of modified universal buffer at pH 11 for the assay of alkaline phosphatase activity and 0.5 mL of PNP solution (50 m*M*). Toluene additions were omitted (Alef et al., 1995). The glass vials were then sealed and incubated for 1 h at 37°C after the contents were thoroughly mixed. After the incubation period, the vials were immediately placed on ice, and 0.5 mL of $CaCl_2$ (0.5 *M*) and 2 mL of NaOH (0.5 *M*) were added. The contents were mixed, and a 0.5-mL aliquot was transferred to 0.65-mL polypropylene tubes for centrifugation at 9300*g* for 1 min. A 200-μL aliquot of the supernatant was then dispensed into a 96-well microplate, and absorbance was measured at 405 nm. Negative controls were prepared by adding 0.5 mL of PNP solution after additions of $CaCl_2$ and NaOH and immediately before centrifugation. Calibration curve regression coefficients ($r^2$) were 0.97 or greater, and phosphatase activity is expressed as μg *p*-nitrophenol g dry soil $h^{-1}$.

Soils were subsequently dried and analyzed for Olsen P with P analysis performed with the ascorbic acid method, as described above. Dried plant samples were digested by microwave-assisted digestion with 3 mL concentrated $HNO_3$, 2 mL concentrated HCl, and 2 mL 30% $H_2O_2$, and analyzed for P, Ca, Fe, K, Mg, Mn, and Zn by inductively coupled plasma optical emission spectroscopy (US Environmental Protection Agency, 1996 [method 3052]).

## Statistical Analyses

All data were analyzed using SAS statistical software version 9.2 (SAS Institute Inc., 2008). All variables were tested for normality using the Shapiro-Wilk test with the PROC UNIVARIATE procedure of SAS. Statistical analyses of the data were performed with a factorial analysis of variance using the PROC GLM (general linear models) procedure with rate, treatment, and their interaction as main effects in the model. Means separation was done using the Ryan-Einot-Gabriel-Welsch multiple range test, with a probability value of 0.05. Regression with indicator variables (PROC GLM) was used to determine differences in slopes of response variables with increasing treatment application rates.

# RESULTS AND DISCUSSION

## Soil, Manure, and Compost Properties

Select soil chemical and physical properties are shown in Table 1. The high-P soil is a topsoil with little erosion having an Olsen P concentration of 28 g $kg^{-1}$, a CCE of 27 g $kg^{-1}$, a TC content of 23 g $kg^{-1}$, and a pH of 7.5. The low-P soil was eroded because of surface irrigation and had greater clay (228 g $kg^{-1}$), pH (7.9), and calcium carbonate content (68 g $kg^{-1}$) as well as lower Olsen P (4.0 g $kg^{-1}$) and TC content (17 g $kg^{-1}$) than the high-P soil.

Select manure and compost properties are presented in Table 2. The manure and compost had similar characteristics as those reported previously from this region (Leytem and Westermann, 2005; Leytem and Bjorneberg, 2009). The manure had greater P, Ca, Zn, C, and N contents than the composted dairy manure. This resulted in higher C:P and C:N ratios in the manure compared with the compost. The compost had greater concentrations of Fe, K, and Mg, whereas the Mn contents of the two materials were similar. When additions of nutrients were calculated on a dry matter basis, the manure and compost treatments received similar P and Ca additions, but the compost had higher amounts of Fe, K, Mg, and Mn added, whereas the manure treatments had greater additions of Zn, C, and N (Table 3). The MAP treatment did not have any additional nutrients other than N and P, with N additions being greater than the manure and compost treatments.

## Soil Test Phosphorus

Olsen P increased with increasing P application rate for all treatments on both the high- and low-P soils (Fig. 1). The rate of increase was significantly different among the treatments following the trend: MAP = compost > manure ($P < 0.001$, $r^2$ 0.99) on the low-P soil and MAP > compost > manure ($P < 0.001$, $r^2 = 0.99$) on the high-P soil. These same trends have been previously reported for calcareous soils receiving manure, compost, and inorganic P sources such as fertilizers (Leytem and Westermann, 2005; Leytem et al., 2005; Leytem and Bjorneberg, 2009). These previous studies reported that the amount of C added with the P source had a large impact on P solubility in the soil, and strong negative trends were found between the C:P ratio of the manures and Olsen P. As in these previous studies, there was a strong negative relationship between the C:P ratio of the source materials and Olsen P in the present study ($P < 0.001$, $r^2 = 0.99$, data not shown).

This reduction in soluble P with increasing C additions is thought to be related to microbial activity in the soils. The addition of C stimulates microbial growth and leads to immobilization of P in microbial tissues. Dehydrogenase activity in the soils was measured to estimate microbial activity (Fig. 2). The addition of manure to the soils significantly increased microbial activity with increasing application rate over that of the control, compost, and MAP treatments in both soils ($r^2 = 0.73$, $P < 0.001$, low-P soil; $r^2 = 0.91$, $P < 0.001$, high-P soil). There was no significant difference in the rate of change in DHA activity between compost and MAP additions in both soils. The

**TABLE 3.** Total Range of Nutrients Added to Calcareous Soils From Southern Idaho to Determine the Effect of Fertilizer, Manure, and Compost Application on Nutrient Availability and Plant Uptake

| Nutrient Added† | Manure | Compost | MAP |
|---|---|---|---|
| P, mg $kg^{-1}$ | 25–200 | 25–200 | 25–200 |
| Ca, mg $kg^{-1}$ | 79–632 | 76–605 | 0 |
| Fe, mg $kg^{-1}$ | 6.0–48.6 | 58.3–466 | 0 |
| K, mg $kg^{-1}$ | 31–244 | 119–956 | 0 |
| Mg, mg $kg^{-1}$ | 31–251 | 44–355 | 0 |
| Mn, mg $kg^{-1}$ | 0.9–7.5 | 1.3–10.8 | 0 |
| Zn, mg $kg^{-1}$ | 1–7.8 | 0.6–4.4 | 0 |
| C, g $kg^{-1}$ | 4.6–36.9 | 1.5–12.1 | 0 |
| N, g $kg^{-1}$ | 0.2–2.0 | 0.1–0.9 | 12–97 |

†Range of total P, C, Ca, Fe, K, Mg, Mn, N, and Zn added to pots determined on a dry matter basis.

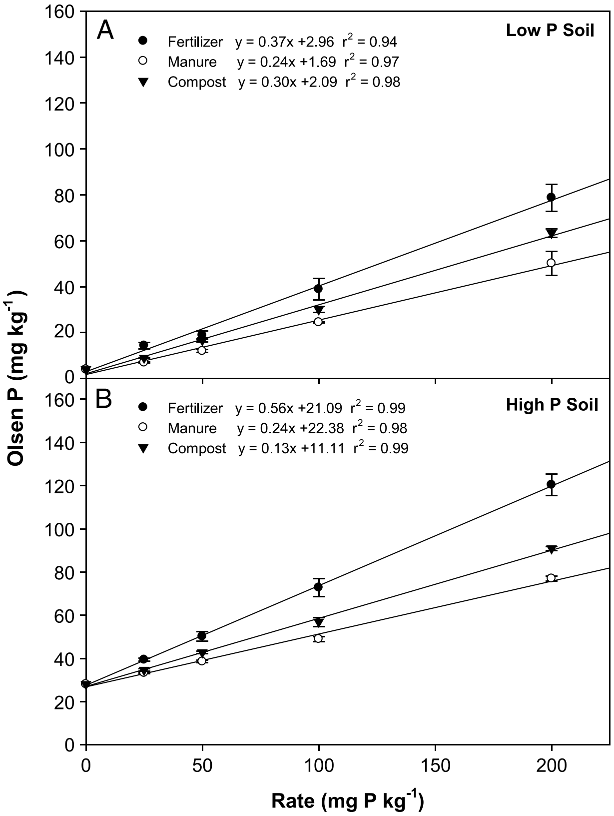


**FIG. 1.** Change in Olsen P with increasing application rates of dairy manure, dairy compost, and fertilizer (MAP) on a low-P (top panel) and high-P (bottom panel) calcareous soil from southern Idaho.

phosphatase activity was also measured as an indication of the mineralization of P occurring in the treated soils (Fig. 3). As with the DHA, the addition of manure to the soils significantly increased the microbial production of phosphatase with increasing application rate over that of the control, compost, and MAP treatments ($r^2 = 0.88$, $P < 0.001$, low-P soil; $r^2 = 0.98$, $P < 0.001$, high-P soil). Again, both the compost and MAP treatments did not show a response in enzyme activity with increasing application rates on both soils. These data provide strong evidence that microbial activity in the treated soils is, at least in part, responsible for the differences in P solubility found between manure, compost, and MAP.

One additional factor that likely influenced the solubility of P in the treated soils was the change in pH with application of the source materials (Fig. 4). The MAP treatment on both soils significantly decreased the soil pH with increasing P application rate ($P < 0.001$), whereas there was little to no effect of additions of manure and compost on soil pH. On the low-P soil, pH decreased from 7.89 to 7.40 with increasing MAP addition, whereas on the high-P soil, pH decreased from 7.53 to 6.82. Solubility and plant availability of P are strongly influenced by pH. Phosphorus solubility (and hence plant availability) is the least between pH units of 7.6 to 7.8, with increasing solubility at pH values both above and below this range (Mengel and Kirkby, 1987). Therefore, as the pH decreased with MAP addition, the solubility of P in these soils would have increased. The change in pH combined with the low microbial activity in the MAP-amended soils could explain why there is enhanced solubility of MAP P compared with P from manure and compost treatments.

## Dry Matter Production and Tissue Nutrient Concentrations

There were no visual signs of deficiency or phytotocity for any of the treatments on either soil. In addition, all of the tissue nutrient concentrations were within sufficiency ranges, although in some cases, there were differences between treatments. There was a significant main effect of application rate on dry matter production on the low-P soil ($P < 0.001$) but no main effect of treatment, whereas on the high-P soil, there was no main effect of either rate or treatment (Tables 4 and 5). The lack of P response in the high-P soil and the significant P response in the low-P soil strongly suggest that P was limiting in the low-P soils but not in the high-P soils, as was expected. The lack of a treatment effect on both low- and high-P soils suggests that, although P source can significantly alter Olsen P concentrations, P source may not have a significant impact on total corn silage yields in an agricultural field. This suggests that P rate may be a more critical predictor of silage yield than Olsen P concentrations when comparing fertilizer, manure, and compost P sources. This also suggests that relationships between Olsen P and silage yield may differ between fertilizer and manure sources of P.

As there was no effect of treatment on dry matter production, we have reported tissue concentrations as these should mirror plant uptake. There was a significant main effect of treatment, rate, and their interaction for tissue concentrations of Ca, K, P, Zn, and Mn on the low-P soil ($P < 0.001$; Table 4),

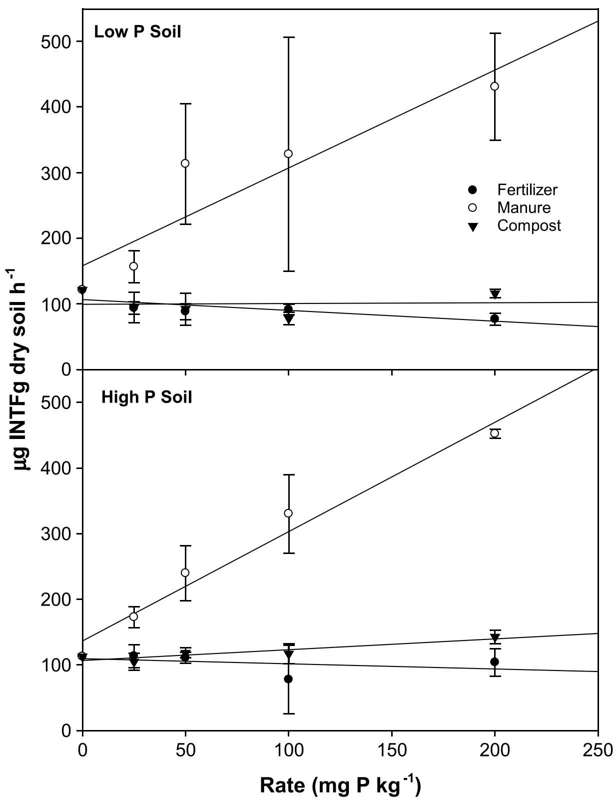


**FIG. 2.** Change in DHA (reported as μg INTF g dry soil $h^{-1}$) with increasing application rates of dairy manure, dairy compost, and fertilizer (MAP) on a low-P (top panel) and high-P (bottom panel) calcareous soil from southern Idaho.

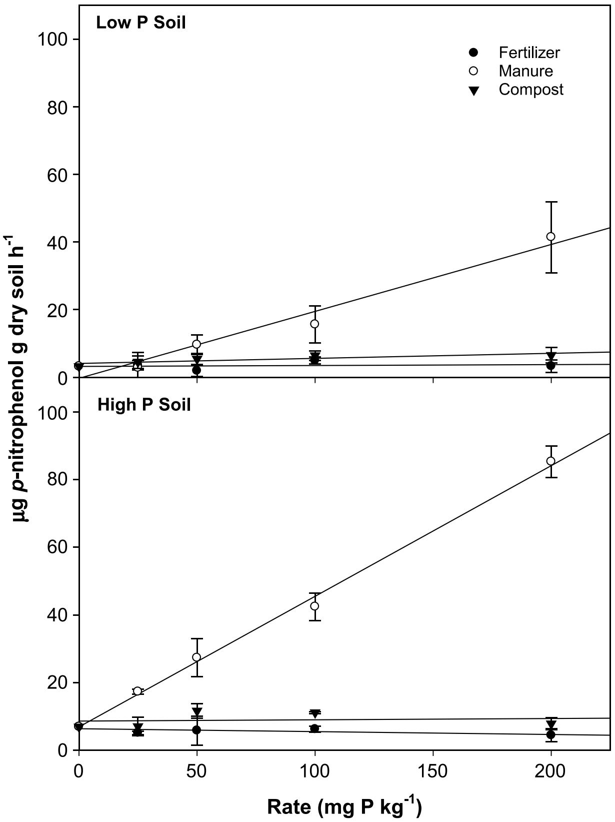


**FIG. 3.** Change in phosphatase activity (reported as µg *p*-nitrophenol g dry soil $h^{-1}$) with increasing application rates of dairy manure, dairy compost, and fertilizer (MAP) on a low-P (top panel) and high-P (bottom panel) calcareous soil from southern Idaho.

whereas tissue concentrations of Mg had a significant treatment effect, but the rate and interaction were not significant ($P < 0.001$). In the high-P soil, there was a significant main effect of treatment and rate and interaction for tissue concentrations of Ca, K, Mg, P, and Zn ($P < 0.001$; Table 5), whereas tissue Mn concentrations showed a significant main effect for treatment but not for rate or the interaction ($P = 0.009$). There was no effect of either treatment or rate on Fe tissue concentrations on either soil; therefore, these data are not shown.

Tissue P concentrations increased with increasing application rate, with the greatest increase occurring with the MAP application, whereas the manure and compost treatments did not differ. This increase in P uptake from the MAP treatments is likely a result of the enhanced P solubility and decrease in soil pH in these treatments, both of which would favor enhanced P uptake by plants (Mengel and Kirkby, 1987). Both the manure and compost also contained significant concentrations of Ca (17 and 12 ppm, respectively), which may have precipitated with orthophosphate to form stable Ca phosphate precipitates, which would not be plant available. In addition, both the manure and compost contained Fe, which could form Fe phosphates, thereby reducing P solubility. Ajiboye et al. (2008) found that calcareous soils amended with dairy manure had significant amounts of strengite ($FePO_4$) formation, whereas these same soils treated with MAP did not.

On the low-P soil, tissue Ca decreased with application of all treatments below that of the control treatment with no difference in the rate of decrease between treatments with increasing application rate. On the high-P soil, tissue Ca decreased with application of all treatments below that of the control, whereas the manure and compost both indicated a greater decrease in Ca tissue concentration with increasing application rates than the MAP treatment. Parsons et al. (2007) reported lower soybean seed Ca concentrations and wheat tissue Ca concentrations with application of manure versus MAP or an unamended control. Cherney et al. (2002) reported that Ca tissue concentration and uptake in orchardgrass and tall fescue decreased after 2 years of manure application compared with commercial fertilizer. Moore et al. (2010) found that calcareous soils with a history of manure application had decreasing corn tissue Ca concentrations with increasing Olsen P (in this instance increasing Olsen P indicated increasing manure application rates), whereas Leytem and Bjorneberg (2009) reported lower seed Ca concentrations in dry beans grown on a calcareous soil that had been fertilized with manure or compost versus commercial fertilizer or an unamended control.

This decrease in Ca tissue concentrations with manure and compost applications could be related to an antagonistic effect of increased soil K concentration on Ca as both the manure and compost treatments had high rates of K application. Marschner (1995) reported that the Ca requirement is augmented when the external concentration of other cations is high because of the ability of cations to displace Ca from binding sites on the surface of the root plasma membrane. This is further supported by the negative relationship between tissue K and tissue Ca of the manure and compost treatments ($r^2 = 0.41$). Another possibility

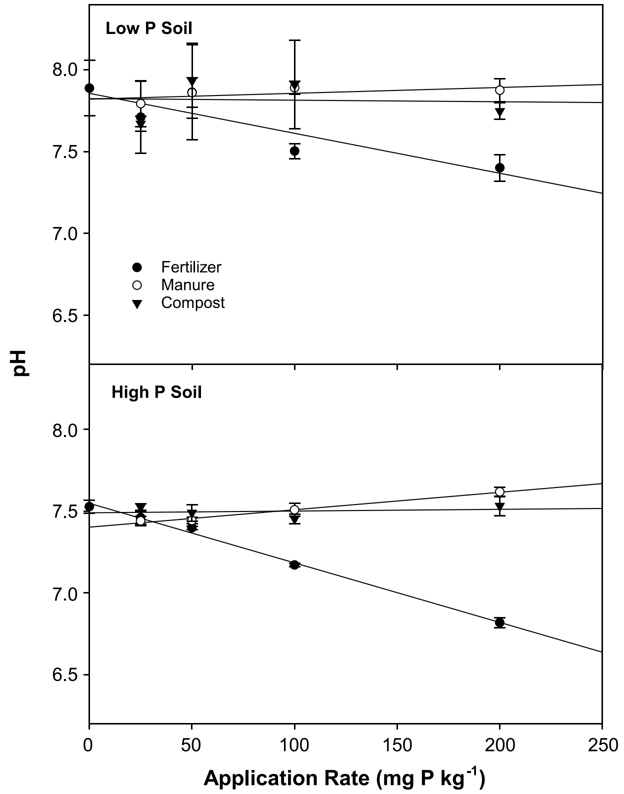


**FIG. 4.** Change in pH with increasing application rates of dairy manure, dairy compost, and fertilizer (MAP) on a low-P (top panel) and high-P (bottom panel) calcareous soil from southern Idaho.

**TABLE 4.** Dry Matter Production and Corn Tissue Concentrations With Increasing P Application Rate of Dairy Manure, Dairy Compost, and MAP on a Calcareous Soil From Southern Idaho With Low Soil Test P

| | Treatment Application Rate, mg P kg$^{-1}$ | | | | |
|---|---|---|---|---|---|
| | 0* | 25 | 50 | 100 | 200 |
| Dry weight | | | | | |
| MAP | 2.08 (0.39) | 3.26 (0.50) | 4.48 (0.89) | 4.32 (0.28) | 5.98 (1.14) |
| Manure | | 2.99 (0.75) | 4.01 (0.57) | 4.44 (0.69) | 4.74 (0.45) |
| Compost | | 3.52 (0.45) | 3.73 (1.01) | 4.43 (0.99) | 4.82 (0.67) |
| Tissue P, g kg$^{-1}$ | | | | | |
| MAP | 2.08 (0.20) | 2.93 (0.14) | 3.12 (0.08) | 4.27 (0.29) | 5.01 (0.18) |
| Manure | | 2.93 (0.27) | 3.48 (0.12) | 3.82 (0.32) | 3.93 (0.39) |
| Compost | | 2.85 (0.09) | 3.03 (0.31) | 3.43 (0.18) | 3.63 (0.27) |
| Tissue Ca, g kg$^{-1}$ | | | | | |
| MAP | 7.08 (0.55) | 6.26 (0.79) | 5.20 (0.56) | 5.69 (0.35) | 5.98 (0.22) |
| Manure | | 5.19 (0.29) | 4.89 (0.21) | 4.60 (0.25) | 4.72 (0.34) |
| Compost | | 5.32 (0.08) | 5.45 (0.74) | 5.31 (0.34) | 4.87 (0.15) |
| Tissue K, g kg$^{-1}$ | 48.33 (1.08) | | | | |
| MAP | | 46.71 (1.73) | 43.46 (2.11) | 43.86 (1.29) | 40.67 (0.69) |
| Manure | | 49.29 (1.56) | 52.95 (1.18) | 54.27 (2.09) | 53.99 (4.51) |
| Compost | | 52.30 (1.00) | 53.33 (0.86) | 56.95 (1.55) | 59.19 (1.64) |
| Tissue Mg, g kg$^{-1}$ | | | | | |
| MAP | 3.66 (0.19) | 3.47 (0.25) | 3.25 (0.19) | 3.58 (0.13) | 4.07 (0.22) |
| Manure | | 3.40 (0.28) | 3.68 (0.14) | 3.82 (0.15) | 3.38 (0.24) |
| Compost | | 3.23 (0.14) | 3.27 (0.27) | 3.11 (0.18) | 2.82 (0.07) |
| Tissue Mn, mg kg$^{-1}$ | | | | | |
| MAP | 125.6 (5.1) | 122.4 (5.6) | 111.0 (9.0) | 124.6 (11.5) | 120.5 (9.7) |
| Manure | | 110.0 (11.1) | 117.7 (7.8) | 104.0 (8.7) | 78.1 (5.4) |
| Compost | | 115.3 (3.6) | 117.9 (7.6) | 115.1 (4.7) | 109.8 (8.0) |
| Tissue Zn, mg kg$^{-1}$ | | | | | |
| MAP | 41.14 (0.43) | 35.46 (2.80) | 36.05 (0.64) | 34.84 (2.68) | 36.03 (4.12) |
| Manure | | 42.21 (3.71) | 49.94 (2.72) | 56.49 (2.66) | 56.47 (7.75) |
| Compost | | 39.8 (0.40) | 36.68 (3.17) | 38.23 (0.93) | 34.1 (0.30) |

Values are presented as mean (S.D.).

*Control soil no treatments added.

is that the addition of Ca along with both the manure and compost applications enhanced formation of Ca-P precipitates, therefore reducing Ca solubility in the treated soils.

On the low-P soils, tissue K increased with the application of both manure and compost over the control, but decreased with the MAP treatment (Table 4). Tissue K decreased with increasing rate of MAP addition, but increased with increasing application rates of manure and compost, with compost showing the greatest increase in tissue K concentrations. On the high-P soil, tissue K increased with application of all treatments over the control, and all treatments showed an increase in tissue K with increasing application rate. Warman and Cooper (2000a) reported a positive linear response in forage tissue K content with increasing application rates of compost and manure and a negative linear response in tissue K with increasing rates of NPK-fertilizer applications. Parsons et al. (2007) reported that corn tissue K concentrations increased with manure treatments versus fertilizer, whereas Cherney et al. (2002) reported that K concentration and uptake in orchardgrass and tall fescue increased after 2 years of manure application compared with commercial fertilizer. As both the manure and compost treatments supplied additional K to the soils, this increased trend in tissue K concentration is not unexpected. The difference in K availability between the MAP treatment on the two soils may be due to the difference in clay content of the two soils, as the greater clay content in the low-P soil may have led to greater binding of K in that soil (Brady, 1990).

On both the low- and high-P soils, tissue Mg concentrations decreased with increasing application rate of compost, whereas the manure treatment did not show any consistent trends, and the application of MAP tended to increase tissue Mg concentrations. Moore et al. (2010) reported that tissue Mg concentrations in silage corn decreased with increasing historical manure application rates, whereas Warman and Cooper (2000b) found some inhibition of Mg uptake by forage in sandy loam soils treated with compost and manure. Conversely, Cherney et al. (2002) did not find a significant difference between tissue Mg or Mg uptake by orchardgrass and tall fescue receiving manure and fertilizer applications. As with Ca, high levels of K may inhibit Mg uptake due to cation competition. The balance between tissue K, Ca, and Mg concentrations is a concern from an animal health perspective as forages with K:(Ca+Mg) ratios greater than 2.2:1 can cause grass tetany in ruminants (Grunes et al., 1970). Although the ratio of K:(Ca+Mg) exceeds 2.2:1 for all the treatments in this study, it is important to keep in mind that plant samples were collected after only approximately 3 weeks, and therefore this may not be representative of the ratio in the corn at maturity.

**TABLE 5.** Dry Matter Production and Corn Tissue Concentrations With Increasing P Application Rate of Dairy Manure, Dairy Compost, and MAP on a Calcareous Soil From Southern Idaho With High Soil Test P

| | Treatment Application Rate, mg P $kg^{-1}$ | | | | |
|---|---|---|---|---|---|
| | 0* | 25 | 50 | 100 | 200 |
| Dry weight | | | | | |
| MAP | 12.12 (0.50) | 12.78 (0.32) | 13.22 (0.27) | 13.12 (0.39) | 12.97 (0.52) |
| Manure | | 13.04 (0.25) | 13.14 (0.37) | 13.44 (0.32) | 12.94 (0.19) |
| Compost | | 12.74 (0.20) | 12.66 (0.28) | 12.76 (0.11) | 12.4 (0.62) |
| Tissue P, g $kg^{-1}$ | | | | | |
| MAP | 2.82 (0.24) | 3.61 (0.16) | 4.11 (0.19) | 5.59 (0.22) | 7.09 (0.16) |
| Manure | | 3.25 (0.11) | 3.50 (0.18) | 4.28 (0.30) | 4.29 (0.16) |
| Compost | | 3.44 (0.19) | 3.59 (0.16) | 3.98 (0.14) | 4.47 (0.13) |
| Tissue Ca, g $kg^{-1}$ | | | | | |
| MAP | 7.86 (0.44) | 7.08 (0.51) | 7.06 (0.44) | 7.21 (0.15) | 7.56 (0.50) |
| Manure | | 7.35 (0.56) | 6.82 (0.21) | 6.45 (0.34) | 5.23 (0.14) |
| Compost | | 6.41 (0.29) | 6.71 (0.40) | 6.16 (0.27) | 5.79 (0.43) |
| Tissue K, g $kg^{-1}$ | | | | | |
| MAP | 50.55 (2.69) | 54.36 (1.38) | 54.21 (1.52) | 56.87 (1.7) | 57.41 (2.36) |
| Manure | | 54.85 (1.37) | 56.43 (0.64) | 60.83 (2.08) | 61.15 (1.44) |
| Compost | | 53.33 (0.94) | 55.61 (1.08) | 58.16 (1.99) | 60.70 (1.80) |
| Tissue Mg, g $kg^{-1}$ | | | | | |
| MAP | 2.94 (0.17) | 3.00 (0.08) | 3.10 (0.13) | 3.40 (0.07) | 3.56 (0.12) |
| Manure | | 3.05 (0.12) | 3.03 (0.07) | 3.21 (0.12) | 2.74 (0.10) |
| Compost | | 2.60 (0.03) | 2.66 (0.09) | 2.54 (0.04) | 2.45 (0.12) |
| Tissue Mn, mg $kg^{-1}$ | | | | | |
| MAP | 153.54 (8.27) | 165.0 (21.2) | 166.9 (13.0) | 161.1 (7.2) | 154.2 (20.3) |
| Manure | | 152.7 (15.3) | 149.1 (15.6) | 155.6 (10.4) | 128.0 (6.8) |
| Compost | | 140.80 (3.1) | 145.6 (8.5) | 148.40 (6.2) | 144.0 (13.9) |
| Tissue Zn, mg $kg^{-1}$ | | | | | |
| MAP | 35.67 (1.82) | 34.11 (2.72) | 34.15 (4.60) | 32.98 (2.18) | 35.89 (1.34) |
| Manure | | 38.69 (2.80) | 41.63 (1.22) | 53.18 (3.95) | 52.84 (4.58) |
| Compost | | 32.81 (1.38) | 36.90 (1.75) | 36.76 (3.24) | 38.03 (1.61) |

Values are presented as mean (S.D.).

*Control soil no treatments added.

On the low-P soil, tissue Mn concentrations decreased with manure and compost application above the 50 mg P $kg^{-1}$ rate, whereas the MAP treatment did not show any clear trends. On the high-P soil, tissue Mn concentrations decreased above the 50 mg P $kg^{-1}$ rate for the MAP treatment, but showed no clear trend for the manure and compost treatments. Moore et al. (2010) reported decreased Mn tissue concentrations in silage corn with increasing historical manure application rates. Warman and Cooper (2000b) reported that forage tissue Mn concentrations were significantly higher in NPK-fertilizer treatments than compost treatments, which they attributed to decreased soil pH in these treatments. Murillo et al. (1997) also reported higher Mn tissue concentrations in clover with urban compost application versus inorganic fertilizer.

The solubility and plant availability of Mn in soil are the lowest at pH values of 7.2 to 7.7; therefore, one would expect that a decrease in pH below this region would enhance Mn uptake. Although the application of MAP on the high-P soil decreased pH from 7.4 to 6.8, there was a decrease in tissue Mn concentration, suggesting that other factors are affecting Mn availability in these soils. One possible explanation for decreased tissue Mn concentrations with compost and manure additions is that complexation of Mn with some organic acids can make Mn unavailable to plants (Laurie and Manthey, 1994). This trend was more pronounced with the manure than the compost treatment, which is likely due to the increased C addition with manure versus compost. The high-P soil did have a higher organic matter content than the low-P soil, which could explain the difference in tissue Mn concentrations between these two soils.

On both the low- and high-P soils, tissue Zn concentrations increased with increasing manure applications up to 100 mg P $kg^{-1}$, whereas tissue Zn concentrations either remained level or decreased slightly with increasing compost and MAP applications. Several studies have reported increased tissue Zn concentrations and Zn uptake by plants when organic amendments were used as a fertilizer source (Pagliari et al., 2009; Wong et al., 1999; Raj and Gupta, 1986). The enhanced uptake of Zn may have been due to a combination of factors. The manure contained significantly more Zn (0.21 mg $kg^{-1}$) than either the compost (0.09 mg $kg^{-1}$) or MAP (no Zn added with MAP), which could have had a positive effect on plant uptake. In addition, the manure treatment applied a greater amount of C than the MAP and compost treatments, which would produce greater amounts of both humic and fulvic acids during decomposition. Stevenson and Ardkani (1972) reported that these acids act as chelating agents and are capable of complexing Zn, thereby rendering it more available to plants. García-Mina et al. (2004)

also reported that Zn-humic complexes significantly increased plant uptake.

## CONCLUSIONS

In summary, the application of manure, compost, and MAP had an impact not only on soil test P and corn tissue P concentrations but also on several other macronutrients and micronutrients. As has been demonstrated in previous studies, the response in soil test P to addition of manure and compost was lower than that of MAP, indicating that there might be less plant available P in soils treated with manure and compost. However, there was no effect of treatment on dry matter production on either soil, which may suggest that soil test P is not always a good indicator of plant available P in manure- and compost-amended calcareous soils. The application of manure and compost increased tissue K concentrations and decreased tissue Ca concentrations, whereas only compost decreased the tissue Mg concentrations. These trends are of concern related to forage production on soils receiving high application rates of manure and composts because K, Ca, and Mg imbalances can lead to grass tetany and milk fever in dairy cattle.

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