Short communication

The effects of *Glycine max* and *Helianthus annuus* on nutrient availability in two soils

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Abstract

The effects of two plant species—soybean (*Glycine max*), and sunflower (*Helianthus annuus*) on nutrient availability in two soils (an organically farmed soil, OF, and a native grassland soil, GS, both Alfisols)—were measured with anion exchange membranes (Plant Root Simulator, PRS^{TM} probes) in a greenhouse study. Vegetation (especially sunflower) in the OF soil caused significant reductions in soil N and K availability (which was interpreted as due to uptake), and significant increases in P, S, Cu, Fe, Mn, and Zn availability. The increases in the latter case were consistent with the results of a previous study showing rhizosphere-enhanced mineralization of native soil organic matter in this soil. Vegetation had no significant effects on Ca, Mg, B, or Al availability in the OF soil and no significant effects on any measured nutrient in the GS soil. Collectively, these results show that the presence of plants can have either a negative or a positive effect on soil nutrient availability, and that plant uptake and soil nutrient availability are interdependent.
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Dijkstra et al. (2006) used a continuous labeling method of naturally ^{13}C-depleted CO_2 in a growth chamber to test for rhizosphere effects on soil organic matter (SOM) decomposition for two C3 plant species (soybean, *Glycine max*, and sunflower, *Helianthus annuus*) in two differently managed soils (organically farmed soil, OF and soil from an annual grassland, GS, both Alfisols dominated by C3 plants). They reported that the presence of plants (soybean, *G. max*; and sunflower, *H. annuus*) caused a 61% increase in soil-derived CO_2 efflux in the OF soil (compared to the no-plant control) whereas presence of plants had a negligible effect in the GS soil ($\leqslant 5\%$ increase). Estimates of rhizosphere-enhanced N mineralization constituted $<6\%$ of N uptake by plants in the OF soil, and soil inorganic N availability as measured by ion exchange membranes (PRS^{TM} probes; Western Ag Innovations, Ltd.) was significantly depleted in the presence of plants in that treatment, suggesting that any enhancement of N mineralization was more than offset by increased plant

uptake where plants were present. In this study, we test the hypothesis that rhizosphere-enhanced SOM decomposition might enhance the availability of other less limiting nutrients in the OF soil.

Details of the experimental design in the previous study have been reported by Dijkstra et al. (2006). Briefly, four replicate pots filled with 7500 g of either the OF or GS soil (both Alfisols) were planted with soybean (*G. max*), sunflower (*H. annuus*), or no seeds, for a total of 12 pots per soil type. Soybean was picked because it is a nitrogen-fixing plant and should rely less on soil N reserves than sunflower which is not a nitrogen fixer. Soils were initially analyzed for exchangeable Ca^{2+}, Mg^{2+}, and K^+ (10 g soil in 50 ml 1 N ammonium acetate), $NaHCO_3^-$-P (2 g soil in 50 ml 0.05 M $NaHCO_3^-$), and Bray-P (2 g soil in 0.5 M HCl plus 1 M NH_4F) using a Jarrell Ash ion coupled plasma spectrophotometer (Thermo Jarrell Ash Corp., Franklin, MA) at A&L Western Agricultural Laboratories (Modesto, CA). Soil total C and total N were analyzed using a dry combustion C and N analyzer (LECO, St. Joseph, MI) and for NH_4^+ and NO_3^- (1 M KCl extraction followed by analysis on a Lachat 8000 flow-injection analyzer with

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Cetac xyz autosampler) at the Oklahoma State University Soil, Water, and Forage Analytical Laboratory, Stillwater, OK.

Plants were grown with 12 h of light, at 25 °C when lights were on and 20 °C when lights were off, and 40% relative humidity and watered daily with deionized water to maintain 80% water holding capacity. Plants were harvested at 57 d after planting, separated into stems, leaves, reproductive organs, and roots were then dried

(65 °C), weighed, ground, and analyzed for nutrient analyses concentrations at A&L Agricultural Laboratories, Modesto, CA. At A&L, total N was determined by Kjeldahl digestion followed by automated colorimetric analysis and P, K, Ca, K, Mg, S, B, Cu, Zn, Mn, Fe, and Al in vegetation were analyzed by inductively coupled plasma (ICP) emission spectroscopy after microwave digestion using a nitric acid hydrogen peroxide digestion mixture.
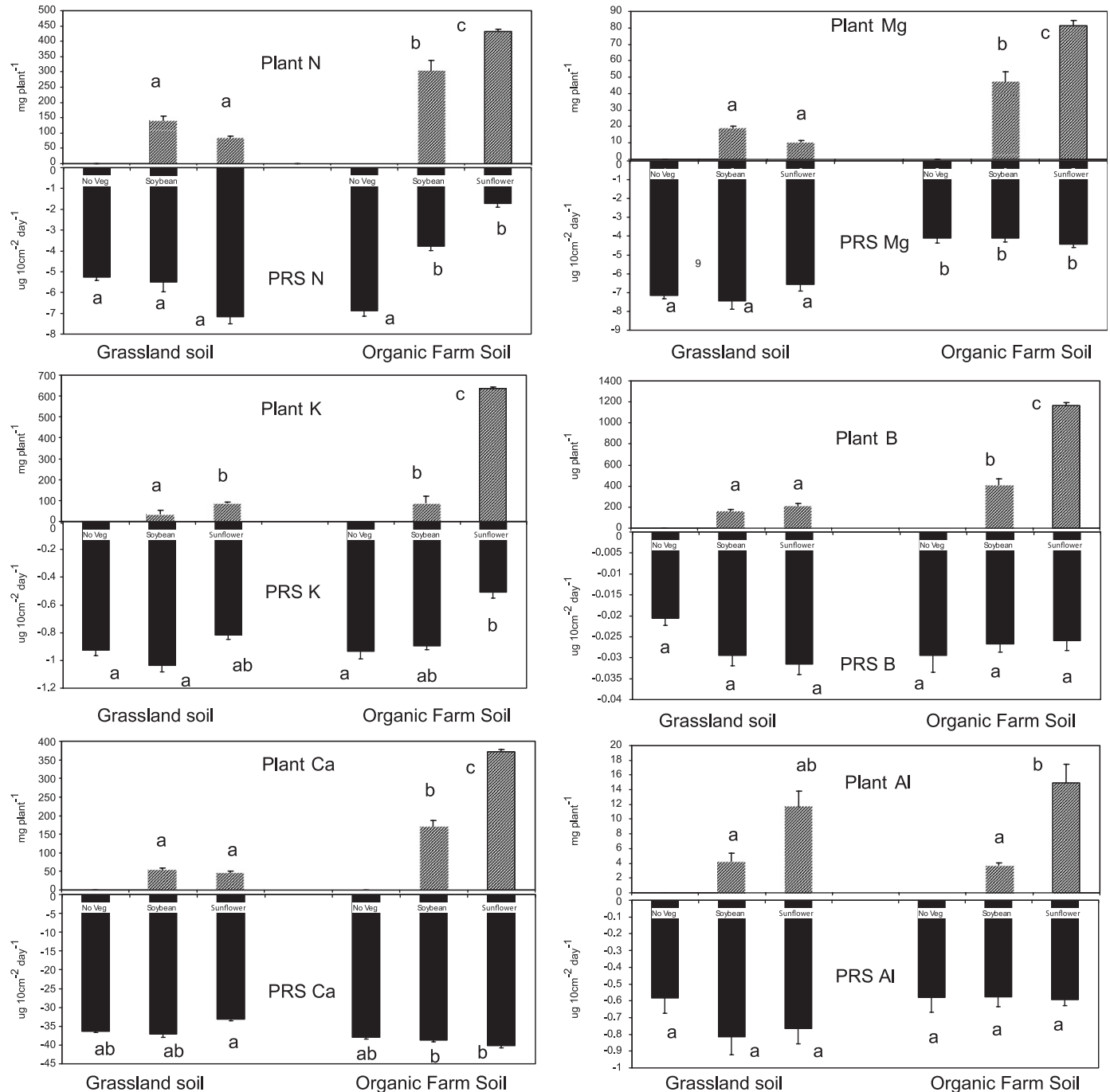

Fig. 1. Plant N, K, Ca, Mg, B, and Al contents compared to Plant Root Simulator (PRS) probe values for these nutrients in a native grassland and organically farmed soil. Bars not sharing the same letters indicate statistically significant differences, Bonferroni post-hoc tests for ANOVA between individual soil and vegetation treatments.

Plant Root Simulator (PRS[TM]) probes (Western Ag Innovations, Inc., Saskatoon, Canada) were used to monitor nutrient availability during the experiment (Hangs et al., 2004). The PRS probes consist of anion or cation exchange membranes imbedded in plastic stakes. The PRS probes were inserted to the 10-cm (top), 20-cm (middle), and 30-cm (bottom) depths in each of the pots at the time of planting. The top PRS probes from the soil were removed after 30 d and replaced with new ones. The second set of PRS top probes as well as the middle and bottom probes were removed at the time of harvesting (57 d). The PRS probes were sent to Western Ag Innovations, Saskatoon, Canada for extraction. At Western Ag, the probes were extracted with 17.5 ml of 0.5 N HCl for 1 h in a zip lock bag, and the extractant was analyzed for NH_4^+ and NO_3^- colorimetrically using a Technicon Autoanalyzer II (TIC 1977). The remaining nutrients were analyzed with the use of ICP emission spectroscopy (Perkin Elmer Optima 3000-DV ICP; Perkin Elmer, Inc. Shelton, CT). The values for both the probes were reported in units of $10 \, \mu mol \, cm^{-2}$ of resin surface. Statistical analyses were performed using Linear Models analysis of variance with
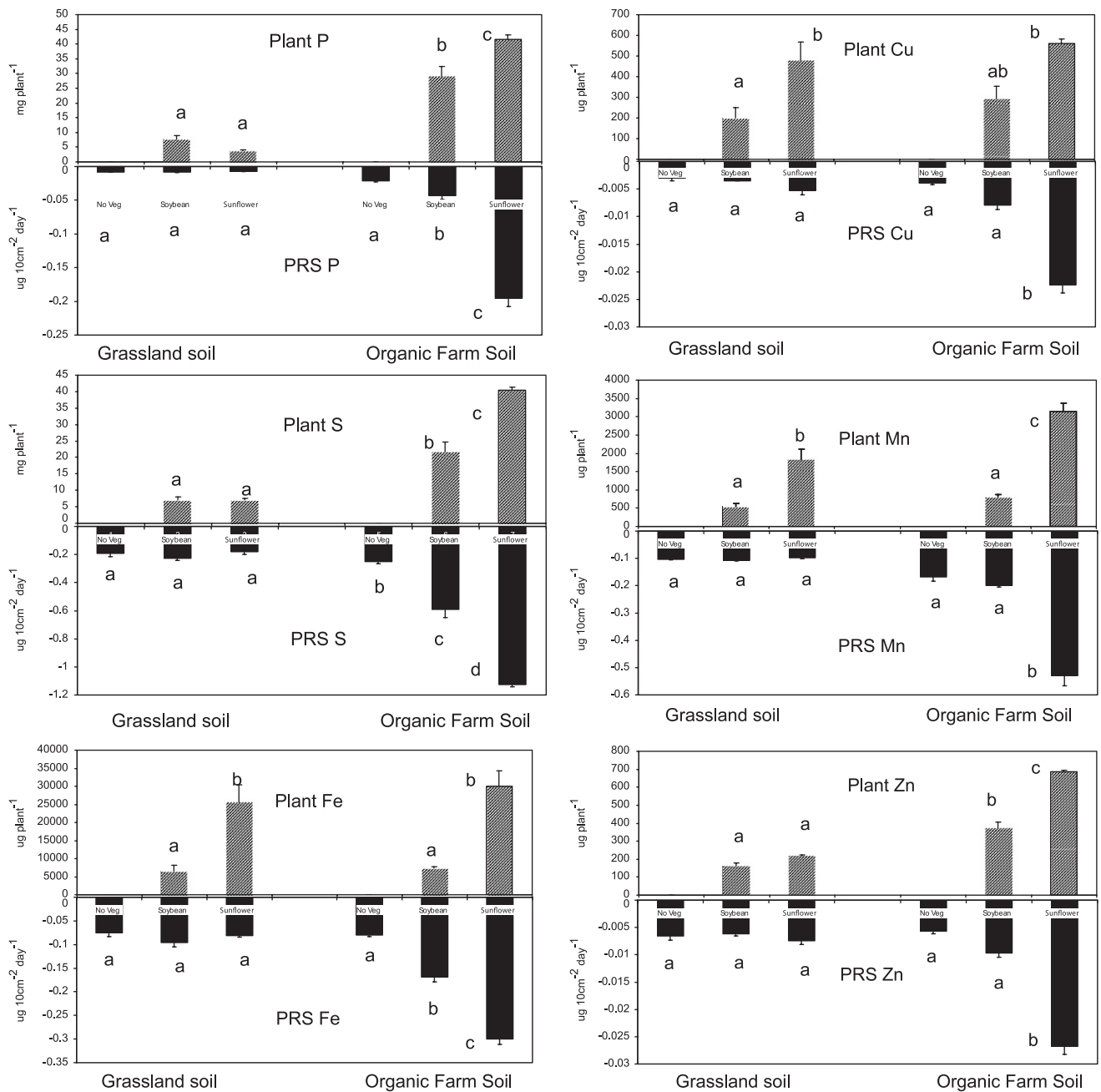

Fig. 2. Plant P, Fe, S, Cu, Mn, and Zn contents compared to Plant Root Simulator (PRS) probe values for these nutrients in a native grassland and organically farmed soil. Bars not sharing the same letters indicate statistically significant differences, Bonferroni post-hoc tests for ANOVA, between individual soil and vegetation treatments.

Bonferroni post-hoc tests for differences between individual treatments with the statistical software DataDesk v. 6.0 (Data Description Inc., Ithaca, NY) .

Figs. 1 and 2 summarize the plant nutrient contents and the PRS probe values for the surface positions at the time of harvest. Results of Bonferroni post-hoc tests for ANOVA between individual soil and vegetation treatments are indicated by letters. At the final harvest, soil type had significant effects on plant contents of all nutrients except Cu, Fe, and Al, and plant type had significant effects on all plant contents of all nutrients. PRS probe values for the 57-d collection of surface samples showed the clearest effects of vegetation and all responses occurred in the OF soil. PRS probe values for the 30-d collection of surface samples (not shown) showed significant effects of soil type but not vegetation. Similarly, the effects of soil type on PRS probe values for the deeper samples on day 57 (not shown) were significant for most nutrients but the effects of vegetation were significant only for P, K, and Al.

The surface, final (57 d) PRS probe results for the OF soils can be divided into three categories: (1) negative effects of plants on nutrient availability, as previously noted by Dijkstra et al. (2006) for N and as we now show to be also true for K (Fig. 1); (2) no effects of plants (Ca, Mg, B, and Al) (Fig. 1); and (3) positive effects of plants (P, S, Fe, Cu, Mn, and Zn) (Fig. 2). The negative effects of plants on PRS probes N and K can be explained in part by comparing initial soil pool sizes with plant uptake (Table 1). Plant uptake equaled 50–120% of initial soil mineral N pools in the OF soils, and thus it is not surprising that plants had a negative effect on PRS mineral N in that case. It is not clear why plants did not have a negative effects on PRS mineral N in the GS soil, where plant uptake equaled 52–85% of initial soil mineral N. Plant K uptake was only a small percentage (5–12%) of initial soil exchangeable values for all but sunflower in the OF soil where it equaled 45% of initial soil value. This is consistent with the reduced PRS K in that particular treatment combination (Fig. 1). In the cases of Ca and Mg, plant uptake values constituted small percentages (1–9%) of initial soil exchangeable pools, consistent with the lack of plant effects on PRS probe values. Plant P uptake constituted relatively small percentages (5–13%) of initial soil extractable P contents, and plant S uptake constituted relatively small percentages of initial soil extractable SO_4^{2-} except in the OF soil planted with sunflower (36%). For both P and S, however, as well as for Cu, Fe, Mn, and Zn,

Table 1
Percent of initial soil contents of some nutrients taken up by plants by day 57

	Grassland soil		Organic farm soil	
	Soybean	Sunflower	Soybean	Sunflower
Mineral N	85	52	86	122
Bray-P	10	5	8	11
Bicarb-P	12	6	9	13
Ca	2	1	2	4
Mg	4	2	5	9
K	5	12	6	45
SO_4^{2-}	3	3	19	36

plants (especially sunflower) substantially increased PRS values in the OF soils. These results are consistent with previous results from this study showing rhizosphere-enhanced decomposition of native SOM in the OF soil, and supports our hypothesis. Alternatively, it could be that the presence of plants mobilized these nutrients by changing soil adsorption characteristics (i.e., by exuding organic anions). In either case, these results support the assertions of Hallsby (1995) and Herman et al. (2006) that soil nutrient availability and plant uptake are interdependent, and that soil nutrient availability can be influenced by plants in both a negative and positive direction.

References

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