Published online December 7, 2017

Agricultural & Environmental Letters

Research Letter

Effect of Multispecies Cover Crop Mixture on Soil Properties and Crop Yield

Mingwei Chu, Sindhu Jagadamma,* Forbes R. Walker, Neal S. Eash, Michael J. Buschermohle, and Lori A. Duncan

Core Ideas

- After 3 yr, soybean yield was higher from multispecies than from single- and double-species cover cropping.
- Multispecies cover cropping had higher soil water and inorganic N content than less-diverse treatments.
- Soil organic C was unaffected by cover crop species diversity.
- Several years of cover cropping are needed to achieve ecosystem benefits.

Abstract: Multispecies cover cropping has become popular in recent years because of the multiple ecosystem benefits compared with single- or double- species cover cropping. However, scientific studies on the effects of multispecies cover cropping—especially in the southern United States—are limited. A field study was initiated in 2013 at the University of Tennessee's Research and Education Center in Milan, TN, to assess the agronomic and soil responses from single-, double-, and multispecies cover cropping in corn (*Zea mays* L.)–soybean [*Glycine max* (L.) Merr.] systems. After 3 yr, we found that a multispecies mixture of legumes, grasses, and *Brassica* spp. significantly increased soybean yield, gravimetric soil water content, and soil inorganic nitrogen as compared to the less-diverse treatments and a no-cover control. However, after 3 yr, cover cropping did not increase soil organic carbon. Although multispecies cover cropping exhibited a positive effect on yield and some soil properties after 3 yr, we plan to continue collecting multiple years of data from this field trial.

According to the United Nations' Food and Agriculture Organization, total food production must be increased 70% by 2050 to feed the growing population (FAO, 2009). At the same time, the agricultural sector's environmental footprint must be reduced considerably to maintain the ecological sustainability and resilience of agronomic production (Foley et al., 2011). The challenge of producing sufficient food for the growing population without compromising our environment is compounded by the diminishing land resources available for cultivation. Cover cropping is an effective, low external-input strategy to address these challenges.

Historically, cover crops have been integrated into cropping systems to meet one or two specific needs, such as soil conservation and weed management; however, more ancillary benefits from growing cover crops have been recognized, including improved water and soil quality, nutrient cycling, moisture conservation, crop productivity, and livestock feed (Hobbs et al., 2008). The ultimate impact of cover cropping depends on several factors, one of the most important being cover crop species. Leguminous cover crops provide additional nitrogen (N) to crops; high biomass–producing nonlegumes control soil erosion, suppress weeds, and improve soil organic matter content; and tap-rooted species such as *Brassica* spp. reduce soil compaction (Chen and Weil, 2010; Ebelhar et al., 1984; Kaspar et al., 2001). Because no single species can deliver all the benefits, mixtures of diverse species of cover crops can be used to provide more multifunctional benefits to agrosystems (Kramberger et al., 2014; Tosti et al., 2014).

Among producers, there is a growing interest in adopting cover crop mixtures, with species selection mostly depending on availability of seeds and anecdotal evidence on performance. The USDA-NRCS recommends region-specific cover crop mixtures including legumes and nonlegumes. Although several potential benefits are expected from the mixtures, growing concerns

Dep. of Biosystems Engineering and Soil Science, Univ. of Tennessee, Knoxville, TN 37996.

Agric. Environ. Lett. 2:170030 (2017)
doi:10.2134/ael2017.09.0030

Received 6 Sept. 2017.
Accepted 22 Nov. 2017.
*Corresponding author (sjagada1@utk.edu).

Abbreviations: PMN, potentially mineralizable nitrogen; SHM, soil health mix; SOC, soil organic carbon.

include increased seed costs as well as higher water demand and difficulty in establishment, management, and termination (Creamer et al., 1997; Smith et al., 2014; Wortman et al., 2012). Therefore, for sustainable crop production, it is extremely important to evaluate the performance of both cover crop mixtures and single- and double-species practices.

Studies on the effects of multispecies cover cropping are limited. A few have focused only on agronomic responses. Wortman et al. (2012), for example, found no agronomic improvement for a sunflower (*Helianthus annuus* L.)–soybean [*Glycine max* (L.) Merr.]–corn (*Zea mays* L.) rotation system resulting from an increased number of cover crop species in the mixture. Smith et al. (2014) found no benefits of growing a cover crop mixture in terms of weed suppression, biomass stability, and subsequent cash crop productivity compared with the best-performing single species. Comparing 18 cover crop treatments in a conventional corn system, Finney et al. (2016) demonstrated that increasing the number of species increased weed suppression and reduced nitrate (NO_3^-) leaching but negatively affected crop yield in the subsequent cropping season; but why this trend occurred was not clear. These studies did not provide evidence for a system-level benefit of multispecies mixes over single and double species or explain the mechanism causing yield depression. The lack of evidence could be the result of the short-term nature (i.e., one or two cropping seasons) of these studies. Finney et al. (2017) reported that increasing functional diversity in cover crop mixtures, rather than increasing number of species, contributed favorably to multifunctionality of cover crops.

Multispecies cover cropping studies are particularly limited in the southern United States—an area representing 40% of all farms and 30% of total farmland in the country (O'Connell et al., 2014). Therefore, the current study was conducted to assess longer-term agronomic and soil responses from integrating single-, double- and multispecies cover crops into west Tennessee's corn–soybean production systems. We hypothesize that a diverse cover crop mixture could provide greater crop yields and more favorable soil properties compared with single- or double-species cover crops.

Materials and Methods

Experimental Location and Treatments

A cover crop field experiment was initiated in 2013 at the University of Tennessee's Research and Education Center in Milan, TN, with the following cover crop treatments: (i) wheat (*Triticum aestivum* L.); (ii) cereal rye (*Secale cereale* L.); (iii) cereal rye and hairy vetch (*Vicia villosa* Roth); (iv) cereal rye and crimson clover (*Trifolium incarnatum* L.); (v) USDA-NRCS's soil health mix (SHM) for Tennessee, comprising cereal rye, oats (*Avena sativa* L.), daikon radish (*Raphanus sativus* var. *niger* J. Kern.), purple top turnips (*Brassica campestris* L.), and crimson clover; and (vi) cover crop-free control. These cover crop species were selected because they represent the most widely adopted cover cropping strategies by producers in Tennessee. The region's mean annual rainfall is 1361 mm, and the soil is classified as a Lexington silt loam (fine-silty, mixed, thermic, Ultic Hapludalf). Before the start of the field trial, soil pH was 6.5 and soil organic carbon (SOC) concentration was 10.9 g kg^{-1}. The treatments were arranged in a randomized complete block experimental design with four replications. Cover crops were drilled soon after the harvest of the preceding no-till crop (corn in 2013 and 2015, soybean in 2014 and 2016) and terminated during March–April. Normal production practices were used to manage the main commodity crop in the experimental plots, including fertilizer application based on soil tests and resulting recommendations from the University of Tennessee. Because this trial will continue for several more years, it is expected to provide answers to the longer-term effect of cover crop integration into annual crop production systems.

Measurement of Soybean Yield

Soybean was harvested using a plot combine harvester equipped with an automatic weighing scale and a moisture meter to adjust the grain moisture content to 130 g kg^{-1}.

Soil Sampling and Processing

Soil samples were collected during October 2016 from 0- to 15-cm depth using 2.5-cm-diameter stainless steel probes. From each plot, samples were collected from 10 to 15 random locations and composited. Composite samples were stored in plastic bags and placed in a cooler with ice packs for transport to the laboratory. Gravimetric soil moisture content was determined using the field-moist samples; all other soil analyses were performed using the air-dried soils passed through a 2-mm sieve.

Soil Analysis

Soil pH was measured on a 1:2 soil/water suspension (Thomas, 1996). Soil organic C was measured by combustion method using a Thermo Flash EA 1112 NC combustion analyzer (Nelson and Sommers, 1996). Soil inorganic N (NO_3 + NH_4) was analyzed using a Skalar Continuous Flow Analyzer after air-dried soil samples were extracted with 2 M potassium chloride (KCl) solution (Mulvaney, 1996). Potentially mineralizable nitrogen (PMN) was measured based on the 7-d anaerobic incubation method (Waring and Bremner, 1964). After extracting soil with deionized water, water extractable NO_3^- was determined using the flow analyzer.

Statistical Analysis

The effect of cover crop species on soil properties and crop yield was determined by analysis of variance (ANOVA) based on the MIXED procedure of SAS v. 9.4 (SAS Institute, 2013). The PDIFF option was used to determine significant differences among treatment means at $P \leq 0.05$.

Results and Discussion

Soil Properties

Soil parameters measured—gravimetric soil moisture content, soil inorganic N, PMN, and total SOC—were investigated in this study.

Gravimetric Soil Moisture Content

The gravimetric soil moisture content was significantly higher for the multispecies treatment compared with the no-cover control ($P = 0.04$). Gravimetric moisture content of other treatments was also higher than the control but not statistically different. Mean values of gravimetric moisture content varied from 17% (for the control) to 21% (for the multispecies mixture) (Fig. 1a). The literature provides ample evidence of increased soil moisture content resulting from integrating cover crops into cash crop systems (Blanco-Canqui et al., 2012; Kaspar et al., 2001; Nielsen et al., 2015; Unger and Vigil, 1998) that could be the result of improved soil structural attributes that enhance infiltration rates and reduce soil water evaporation (Colla et al., 2000; Lotter et al., 2003). A more recent study (Wortman et al., 2012) also showed that soil moisture content was the highest with the integration of an eight-species cover crop mixture for 3 yr compared with less-diverse mixtures and cover crop-free control. Although we found that soil moisture was conserved by growing a cover crop mixture, our finding is based on a single time point determination of gravimetric moisture content after the harvest of soybean in October 2016.

Soil Inorganic N

Soil inorganic N (potassium chloride-extractable NH_4 + NO_3) varied significantly across treatments at $P = 0.03$ (Fig. 1b). The combination of cereal rye and hairy vetch showed statistically higher inorganic N (20.5 mg kg^{-1}) compared with the single-species cereal rye (15.8 mg kg^{-1}) and no-cover control (15.5 mg kg^{-1}); the values from the other treatments fell in between. Soil N transformations, in general, are strongly influenced by the type of cover crop species; for example, grass species scavenge N from soil, whereas legume species fix atmospheric N and supply a part of the fixed N to soil when the plant biomass decomposes (Blanco-Canqui et al., 2015; Dabney et al., 2001; Finney et al., 2017). Our data supported this general understanding by showing higher soil inorganic N from legume-incorporated double- and multispecies treatments than from monoculture grasses such as wheat and cereal rye. Despite increased soil inorganic N results, water-extractable NO_3–N was statistically similar across cover crop treatments (1.32–2.06 mg kg^{-1}), indicating no significant risk of soluble N loss through leaching and runoff. As expected, cover crops are effective at limiting off-site movement of NO_3, an important environmental effect considering the hypoxic zone in the Gulf of Mexico.

Potentially Mineralizable N

Because the soil inorganic N level does not accurately represent the plant available N and varies with soil sampling time (Horwath, 2015; Zhang et al., 2004), we determined PMN based on a 7-d incubation experiment, taking into account the N that is available throughout the growing season. Soil PMN varied significantly across the cover crop treatments, with mean values ranging from 38 to 48 mg kg^{-1} at $P = 0.01$ (Fig. 1c). Multispecies SHM and double-species cereal rye + crimson clover treatments showed the highest PMN, and the cover crop-free control showed the lowest. Regardless of the treatments, PMN values were 2.3 to 2.5 times higher than the levels of soil inorganic N, which equates to 50 to 60 kg N ha^{-1}, confirming previous findings that fertilizer recommendations based on soil inorganic N levels often lead to overfertilization for succeeding crops (Horwath, 2015).

Soil Organic Carbon

Total SOC content ranged from 10.1 to 11.4 g kg^{-1} and was not significantly different across cover crop treatments. In addition, these values are comparable to the baseline SOC content (10.9 g kg^{-1}) measured before the start of the experiment in 2013. With the increased input of above- and belowground biomass to the soil, it is reasonable to expect increased SOC by cover cropping compared with no-cover cropping. However, this effect is strongly influenced by several factors, including duration of cover cropping, antecedent SOC content, soil type, and climate (Blanco-Canqui et al., 2015). The

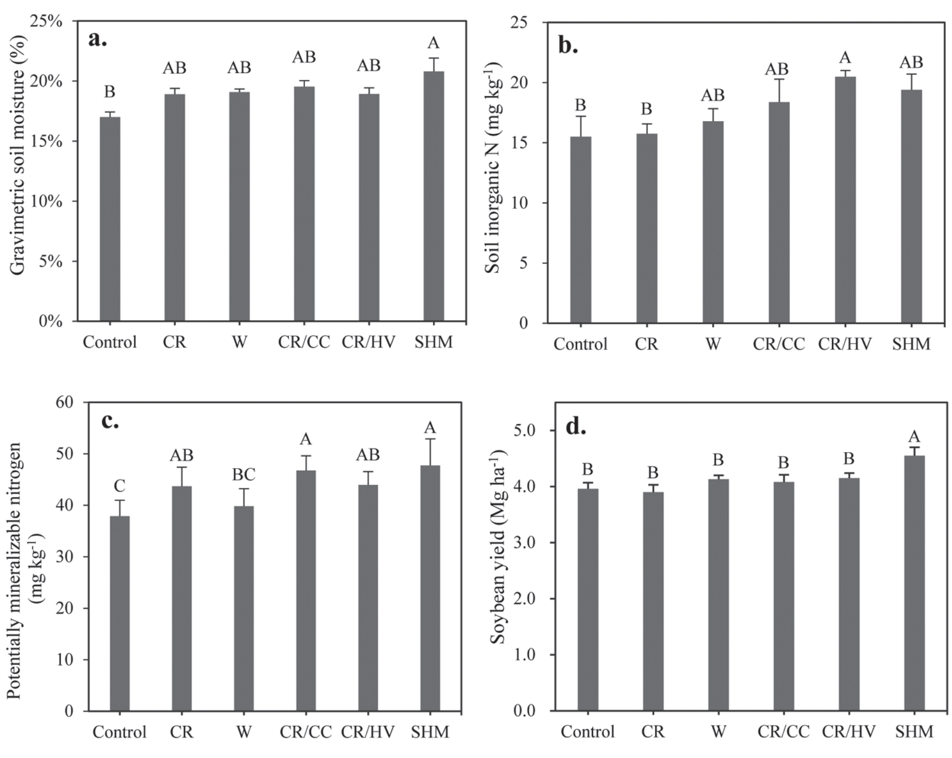

Fig. 1. Effect of cover crop treatments on (a) gravimetric soil moisture, (b) soil inorganic N, (c) potentially mineralizable N, and (d) soybean grain yield. CC, crimson clover; CR, cereal rye; HV, hairy vetch; SHM, soil health mix (cereal rye, whole oats, purple top turnips, daikon radish, and crimson clover); W, wheat. Different uppercase letters over the bars denote statistically different means at $P \leq 0.05$. Error bars represent standard error of the mean with $n = 4$.

lack of favorable response of SOC to cover cropping in this study can be attributed to the experiment's shorter duration (4 yr) and to Tennessee's hot and humid climatic conditions that favor accelerated SOC mineralization (Davidson and Janssens, 2006; Fang et al., 2005). Previous studies also reported no measurable differences in SOC in the first few years of cover cropping (Acuña and Villamil, 2014; Blanco-Canqui et al., 2014). Additionally, no-till systems exhibit a stratification of SOC, with the highest content observed in the top few centimeters of soil. The depth at which we collected the sample, 0 to 15 cm, may have diluted the differences in the surface layer's organic C levels.

Soybean Yield

Soybean yield from the multispecies SHM was significantly higher (4.55 Mg ha^{-1}) than from all other treatments (Fig. 1d). Although yield from other cover crop treatments, except cereal rye, was numerically higher than that from the no-cover control, the differences were not statistically significant. Cereal rye yield was 3.9 Mg ha^{-1}, lower but not significantly different than the control, which could be a result of the cereal rye's reduced N supply to the soil. Cereal rye's negative effect on the subsequent cash crop was also reported by Finney et al. (2016). Although multispecies SHM treatment produced a 15% higher yield compared with the control in 2016, the previous yields of soybeans (in 2014) and corn (in 2013 and 2015) were not significantly different across the cover crop treatments (data not shown). The lack of yield response during the first few years of cover cropping was also reported in studies conducted by several researchers, including Decker et al. (1994), Andraski and Bundy (2005), Wortman et al. (2012), Smith et al. (2014), and Finney et al. (2016). Our findings indicate that beyond the first few years, cover cropping with more diverse species could positively affect the productivity of row crops.

Conclusions

This study evaluated the crop yield and soil properties from growing a multispecies cover crop mixture compared with those from the less-diverse single- and double-species cover crops and no-cover control in a corn–soybean production system in west Tennessee. After 3 yr of establishing a multispecies cover crop mixture, we found increased soybean yield in comparison with less-diverse cover crops and a no-cover control. We also found increased soil inorganic N and soil moisture content from plots planted with double- and multispecies cover crops compared with plots with single-species and no-cover crops. Soil organic C content was unaffected by the cover crop treatments and duration of cover cropping. Because these results are based on data from a single growing season in one location, we plan to collect multiyear data before making robust conclusions. Nevertheless, to the best of our knowledge, this is the first study from the southeastern United States reporting both agronomic and soil responses from a multispecies cover cropping strategy.

References

Acuña, J.C.M., and M.B. Villamil. 2014. Short-term effects of cover crops and compaction on soil properties and soybean production in Illinois. Agron. J. 106:860–870. doi:10.2134/agronj13.0370

Andraski, T.W., and L.G. Bundy. 2005. Cover crop effects on corn yield response to nitrogen on an irrigated sandy soil. Agron. J. 97:1239–1244. doi:10.2134/agronj2005.0052

Blanco-Canqui, H., M. Claassen, and D. Presley. 2012. Summer cover crops fix nitrogen, increase crop yield, and improve soil–crop relationships. Agron. J. 104:137–147. doi:10.2134/agronj2011.0240

Blanco-Canqui, H., R.B. Ferguson, V.L. Jin, M.R. Schmer, B.J. Wienhold, and J. Tatarko. 2014. Can cover crop and manure maintain soil properties after stover removal from irrigated no-till corn? Soil Sci. Soc. Am. J. 78:1368–1377. doi:10.2136/sssaj2013.12.0550

Blanco-Canqui, H., T.M. Shaver, J.L. Lindquist, C.A. Shapiro, R.W. Elmore, C.A. Francis, et al. 2015. Cover crops and ecosystem services: Insights from studies in temperate soils. Agron. J. 107:2449–2474. doi:10.2134/agronj15.0086

Chen, G., and R.R. Weil. 2010. Penetration of cover crop roots through compacted soils. Plant Soil 331:31–43. doi:10.1007/s11104-009-0223-7

Colla, G., J.P. Mitchell, B.A. Joyce, L.M. Huyet, W.W. Wallender, and S.R. Temple. 2000. Soil physical properties and tomato yield and quality in alternative cropping systems. Agron. J. 92:924–932. doi:10.2134/agronj2000.925924x

Creamer, N.G., M.A. Bennet, and B.R. Stinner. 1997. Evaluation of cover crop mixtures for use in vegetable production systems. HortScience 32:866–870.

Dabney, S., J. Delgado, and D. Reeves. 2001. Using winter cover crops to improve soil and water quality. Commun. Soil Sci. Plant Anal. 32:1221–1250. doi:10.1081/CSS-100104110

Davidson, E.A., and I.A. Janssens. 2006. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature 440:165–173. doi:10.1038/nature04514

Decker, A.M., A.J. Clark, J.J. Meisinger, F.R. Mulford, and M.S. McIntosh. 1994. Legume cover crop contributions to no-tillage corn production. Agron. J. 86:126–135. doi:10.2134/agronj1994.00021962008600010024x

Ebelhar, S.A., W.W. Frye, and R.L. Blevins. 1984. Nitrogen from legume cover crops for no-tillage corn. Agron. J. 76:51–55. doi:10.2134/agronj1984.00021962007600010014x

Fang, C., P. Smith, J.B. Moncrieff, and J.U. Smith. 2005. Similar response of labile and resistant soil organic matter pools to changes in temperature. Nature 433:57–59. doi:10.1038/nature03138

Finney, D.M., E.G. Murrell, C.M. White, B. Baraibar, M.E. Barbercheck, B.A. Bradley, et al. 2017. Ecosystem services and disservices are bundled in simple and diverse cover cropping systems. Agric. Environ. Lett. 2:1–5.

Finney, D.M., C.M. White, and J.P. Kaye. 2016. Biomass production and carbon/nitrogen ratio influence ecosystem services from cover crop mixtures. Agron. J. 108:39–52. doi:10.2134/agronj15.0182

Foley, J.A., N. Ramankutty, K.A. Brauman, E.S. Cassidy, J.S. Gerber, M. Johnston, et al. 2011. Solutions for a cultivated planet. Nature 478:337–342. doi:10.1038/nature10452

Food and Agriculture Organization. 2009. How to feed the world in 2050. FAO, Rome.

Hobbs, P.R., K. Sayre, and R. Gupta. 2008. The role of conservation agriculture in sustainable agriculture. Philos. Trans. R. Soc. B 363:543–555. doi:10.1098/rstb.2007.2169

Horwath, W.R. 2015. Soil respiration tests as predictors of nitrogen mineralization potential. In: G. Mooso, et al., editors, Proceedings of the Western Nutrient Management Conference. 5–6 Mar. 2015. Vol. 11. Western Region Nutrient Management Coordination Committee, Reno, NV. p. 1–5.

Kaspar, T., J. Radke, and J. Laflen. 2001. Small grain cover crops and wheel traffic effects on infiltration, runoff, and erosion. J. Soil Water Conserv. 56:160–164.

Kramberger, B., A. Gselman, J. Kristl, M. Lešnik, V. Šuštar, M. Muršec, et al. 2014. Winter cover crop: The effects of grass–clover mixture proportion and biomass management on maize and the apparent residual N in the soil. Eur. J. Agron. 55:63–71. doi:10.1016/j.eja.2014.01.001

Lotter, D.W., R. Seidel, and W. Liebhardt. 2003. The performance of organic and conventional cropping systems in an extreme climate year. Am. J. Altern. Agric. 18:146–154. doi:10.1079/AJAA200345

Mulvaney, R.L. 1996. Nitrogen-inorganic forms. In: D.L. Sparks, et al., editors, Methods of soil analysis. Part 3. Chemical methods. SSSA and ASA, Madison, WI. p. 1123–1184.

Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. In: D.L. Sparks, et al., editors, Methods of soil analysis. Part 3. Chemical methods. SSSA and ASA, Madison, WI. p. 961–1010.

Nielsen, D.C., D.J. Lyon, G.W. Hergert, R.K. Higgins, F.J. Calderón, and M.F. Vigil. 2015. Cover crop mixtures do not use water differently than single-species plantings. Agron. J. 107:1025–1038. doi:10.2134/agronj14.0504

O'Connell, S., J.M. Grossman, G.D. Hoyt, W. Shi, S. Bowen, D.C. Martcorena, et al. 2014. A survey of cover crop practices and perceptions of sustainable farmers in North Carolina and the surrounding region. Renew. Agric. Food Syst. 30:550–562. doi:10.1017/S1742170514000398

SAS Institute. 2013. The SAS system for Microsoft Windows. Release 12.1. SAS Inst., Cary, NC.

Smith, R.G., L.W. Atwood, and N.D. Warren. 2014. Increased productivity of a cover crop mixture is not associated with enhanced agroecosystem services. PLoS One 9:E97351. doi:10.1371/journal.pone.0097351

Thomas, G.W. 1996. Soil pH and soil acidity. In: D.L. Sparks, et al., editors, Methods of soil analysis. Part 3. Chemical methods. SSSA and ASA, Madison, WI. p. 475–490.

Tosti, G., P. Benincasa, M. Farneselli, F. Tei, and M. Guiducci. 2014. Barley–hairy vetch mixture as cover crop for green manuring and the mitigation of N leaching risk. Eur. J. Agron. 54:34–39. doi:10.1016/j.eja.2013.11.012

Unger, P.W., and M.F. Vigil. 1998. Cover crop effects on soil water relationships. J. Soil Water Conserv. 53:200–207.

Waring, S., and J. Bremner. 1964. Ammonium production in soil under waterlogged conditions as an index of nitrogen availability. Nature 201:951–952. doi:10.1038/201951a0

Wortman, S.E., C.A. Francis, M.L. Bernards, R.A. Drijber, and J.L. Lindquist. 2012. Optimizing cover crop benefits with diverse mixtures and an alternative termination method. Agron. J. 104:1425–1435. doi:10.2134/agronj2012.0185

Zhang, M., R.E. Karamanos, L.M. Kryzanowski, K.R. Cannon, and T.W. Goddard. 2004. A single measurement to predict potential mineralizable N. Alberta Agriculture and Forestry, Alberta, CA.