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The soil health tool—Theory and initial broad-scale application

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ABSTRACT

Soil health has traditionally been judged in terms of production; however, it recently has gained a wider focus with a global audience, as soil condition is becoming an environmental quality, human health, and political issue. A crucial initial step in evaluating soil health is properly assessing the condition of the soil. Currently most laboratory soil analyses treat soils as non-living, non-integrated systems. Plant available nutrients have traditionally been estimated with methods that utilize harsh chemical extractants in testing soil for inorganic N, P, K, and micronutrients. Complementary methods, including soil texture, pH, and total soil organic matter, also do not evaluate biological soil aspects. In this paper we introduce and describe the theory behind the Soil Health Tool, focusing on two objectives: 1) to estimate plant available N, P, and K; and 2) to provide an indication of soil health with respect to nutrient and C cycling. The Soil Health Tool is an integrative soil testing approach that measures inorganic N, P, and K with a soil extractant comprised of organic acids. It also estimates potentially mineralizable N and P as influenced by water extractable organic C and N and microbial soil respiration. The Soil Health Tool was designed for use in commercial soil testing laboratories and uses rapid, cost-effective procedures. The tool also offers insight into the complex interactions between soil chemistry and biology and providing additional value to producers through improved plant available nutrient estimates as well as an indication of the soil health status as related to C, N, and P cycling.

1. Introduction

Soil health is normally viewed in terms of production, which could be biomass production (McBratney et al., 2012) or productivity indices relative to fundamental soil properties. As early as the 1930s, studies were conducted with regards to the fitness of soils for crop production based on increasing yields from a profit standpoint. In recent years, soil quality is beginning to have a wider focus with a global audience, as soil condition is becoming an environmental quality, human health, and political issue. Soil is the keystone of food security, water security, climate change mitigation, and biodiversity protection (McBratney et al., 2014).

Soil health or quality has been defined in many ways that usually include various aspects of physical and chemical soil properties and some biological indicators. The Food and Agriculture Organization of the United Nations (FAO) describes soil health as the "capacity of soil to function as a living system, with ecosystem and land use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health. Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots; recycle essential plant nutrients; improve soil structure with positive repercussions for soil water and nutrient holding capacity, and ultimately improve crop production" (FAO, 2008). Simply put, the soil is a living ecosystem deserving of equivalent analyses as animal or plant habitats.

From an agricultural standpoint we have long focused solely on the soil physical and chemical properties that relate to plant production, neglecting the inherent biological components of soil that contribute to its overall health. In 1 m^3 of agricultural soil there is between 1200 and 1700 kg of soil containing approximately 2.3%–2.6% of the soil's carbon in the microbial biomass (Anderson and Domsch, 1989). Throughout their life cycle, the microbial biomass (bacteria and fungi) immobilize N during growth and release plant-available N and P upon their death. Microbial nutrient cycling can provide enough N and P to produce a crop without the addition of fertilizers. When the agricultural community accepts the fact that the soil is a biological system and manages it accordingly, it will be able to restore and build soil health while concurrently reducing input costs and maintaining or improving crop yields (Stika, 2013). Additionally, producers have the potential to significantly reduce the negative environmental effects of modern farming practices by managing the soil as a living ecosystem and

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enhancing its inherent nutrient cycling ability.

An important initial step in improving soil health is properly assessing the current soil condition. In most current laboratory analyses, soils are treated as non-living, non-integrated systems, and traditional soil testing methods include harsh chemical to extract inorganic N, P, and K and sometimes micronutrients. These chemical extractants (e.g., sulfuric, hydrochloric, nitric, phosphoric, diethylenetriaminepentaacetic, and ethylenediametetraacetic acids) do not occur in nature. Traditional methods also determine soil texture, pH, and total soil organic matter (SOM); however, organic matter provides a gross indication of soil biological function at best. In this paper we introduce a new method to estimate plant available N, P, and K; and provide an indication of soil health focused on nutrient and C cycling. The Soil Health Tool integrates several measurements soil biological and chemical properties utilizing methods designed for commercial soil testing laboratories.

This paper serves as an introduction to the Soil Health Tool developed by USDA Agricultural Research Service (USDA-ARS) scientists in Temple, TX, as the culmination of more than 15 years of soil testing research. The Soil Health Tool analyzes soil nutrient dynamics recognizing soil is a living, highly-integrated, and evolved system. In contrast to soil fertility research and practice in the past, it utilizes an integrated approach that synthesizes both the Newtonian and Darwinian approaches to science, as viewed by physicists and ecologists. As it relates to soil fertility, the Newtonian scientific approach views soil in ever increasing simplistic components that dictate a reliable pattern or law (Harte, 2002); therefore, concentrations of N, P, and K are determined chemically and used to determine a predicted production response. This simplistic "component" view does not account for the biological, or more broadly, ecological nature of the soil. In contrast, the Darwinian scientific approach views each component of a particular habitat or species as ever increasingly complex and seeks to understand the complex interactions. The Soil Health Tool combines both scientific viewpoints in the examination of the chemical and biological sources of soil fertility. In this paper we will: (1) describe the theory and methods behind the Soil Health Tool; and (2) present results of soils under corn, wheat, and soybean production when analyzed with the Soil Health Tool.

2. Materials and methods

2.1. Sample procurement

More than 21,000 soil samples from throughout the contiguous United States have been analyzed with the Soil Health Tool at the Grassland, Soil and Water Research Laboratory, Temple, TX. Hundreds of thousands samples have been analyzed using the Soil Health Tool by commercial laboratories. The data used in this preliminary analysis are comprised of 432 soil samples obtained from the top 15 cm of the upper soil profile from 26 states collected in 2014 (Table 3). These samples were chosen because they had corresponding yield data on major crops (corn, wheat, soybean) and management information for a variety of practices including cultivated and no-till cropland, pasture land, and land with and without cover crops. Plant available N and P in the soil, fertilizer additions, soil health scores, and crop yields were analyzed for each of these crops. Statistical analyses (linear regression and descriptive statistics) were performed using SigmaPlot 12.0 (Systat Software, Inc.).

2.2. Soil C, N, and P analysis

The Soil Health Tool integrates measurements of water extractable organic C; water extractable total N; water and H3A extractable NO_3-N, NH_4-N, and PO_4-P; H3A extractable Al, Fe, Ca, P, and K; and CO_2-C evolution after 24 h incubation (Haney et al., 2008a, 2010a) to estimate plant available N, P, and K, and provide an indication of soil health as related to nutrient and C cycling.

Microbial food sources, namely organic N and C, also strongly influence soil microbial activity and nutrient cycling; however, traditional soil tests typically only estimate one form of plant available N (NO_3-N and ignore other plant available inorganic and organic forms (e.g., NH_4-N). In fact, some laboratories do not test for N, which ignores the fact that soils do contribute inorganic and organic N to plants. The soil organic N pool, which is highly related to the water extractable organic C pool, contains potentially mineralizable N that can be released to the soil in inorganic N forms that are readily plant available (Haney et al., 2008b, 2012).

Traditional tests often use the SOM test and a simple, universal conversion factor to estimate soil C, but the soil C pool is large and mostly inactive, so it provides little information related to soil nutrient cycling. In contrast, water extractable organic C (WEOC) reflects the quality of soil organic C as it provides the energy source for soil microbial activity (Haney et al., 2012). The contrast in soil C forms can be clearly seen with the following example. A soil with 3% SOM when measured with the combustion method and a 0–7.6 cm sampling depth represents a soil C concentration of 20,000 mg C/kg soil. In contrast, water extractable C from the same soil typically ranges from 100 to 500 mg C/kg soil for cropland and 250 to 1000 mg C/kg soil for grassland; therefore, the Soil Health Tool estimates this active pool of soil C. Similarly, the Soil Health Tool uses the water extractable organic C: N (not the total soil C: N) because it is a more sensitive indicator and better respects active soil pools (Haney et al., 2012).

Traditional soil tests typically utilize extractants including Mehlich 3 (Mehlich, 1984) and Olsen (Olsen et al., 1954), which were designed for certain soil pH ranges; however, these extractants are often applied outside their intended pH range because of the benefits of uniform procedures and rapid analysis. This produces inaccurate predictions of plant available P because of the influence of soil pH on soil-solution chemistry (Nelson et al., 1953; Menon et al., 1988) and P solubility (Golterman, 1998; Sharpley, 1993). Thus, the Soil Health Tool uses the H3A extractant (Haney et al., 2006, 2010a), which is composed of weak organic acids that mimic plant root exudates. H3A has been shown to closely match results from the "gold standard" plant available P test that uses FeAlO strip results (Haney et al., 2016).

Each soil sample was dried at 50 °C (Haney et al., 2004), ground to pass a 2-mm sieve, and weighed into two 50-ml centrifuge tubes (4 g each). One 4-g sample was extracted with 40 ml of DI water, and the other was extracted with H3A (Haney et al., 2006, 2010a). The water and H3A extracts were analyzed on a Seal Analytical rapid flow analyzer (RFA) for NO_3-N, PO_4-P, and NH_4-N. The water extract was also analyzed on a Teledyne-Tekmar Apollo 9000C:N analyzer for water extractable organic C and total water extractable N (WEN). The H3A extract was also analyzed on a Varian ICP for Ca, Fe, Al, P, and K.

2.3. CO_2 respiration

Soil research utilized steady state conditions for estimating soil microbial activity (i.e., constant temperature, oxygen, and water content). This was an understandable initial approach for the laboratory; however, the drying/rewetting cycle that occurs with rainfall and irrigation events creates a highly dynamic, microbial-driven nutrient cycling mechanism in nature and agricultural fields (Haney and Haney, 2010). Thus the Soil Health Tool utilizes the natural drying-rewetting cycle in the soil in its estimates of soil microbial activity and plant available N and P.

Almost 100 years ago, researchers recognized that CO_2 respiration is an indicator of soil fertility (Gainey, 1919; Lebedjantzev, 1924; Birch, 1960). The microbial biomass plays the leading role in organic matter decomposition and nutrient cycling and is highly related to active pools of potential C and N mineralization (Franzluebbers et al., 1999, 2000). The microbial population oxidizes organic compounds from SOM and generates CO_2. This release of CO_2 is coupled with energy production, nutrient cycling, and microbial growth. Microbes sequester C, N, and P in a ratio of roughly 100:10:1, making C the driver of the soil nutrient-microbial recycling system.

Soil microbial composition, adaptability, and structure are a result of the environment they inhabit, and their populations adapted to the temperature, moisture levels, soil structure and texture, crop and management inputs, as well as soil nutrient content of that habitat (Franzluebbers et al., 1996a, 2001; Haney et al., 2010b). Microbial existence and activity are highly related to soil quality, and their activity can be used to evaluate the effect management practices on soil carbon dynamics (Franzluebbers et al., 1994, 1995a,b; Haney et al., 2008b).

The CO_2-C released by soil microbes in 24 h after the soil has been dried and rewetted is an indicator of soil microbial activity that can be used as a rapid biological soil quality indicator as it is highly related to soil fertility (Franzluebbers et al., 1995a, 1996b; Haney et al., 2001, 2004, 2008b; Haney and Franzluebbers, 2009). Since soil microbial activity is the cornerstone of soil health in terms of nutrient and C cycling, CO_2-C evolution (Haney et al., 2008a) is a critical component of the Soil Health Tool. To determine CO_2 respiration a 40-g subsample was weighed into one 50-ml plastic beaker perforated to reach field capacity through capillary action (Haney and Haney, 2010). One-day CO_2 evolution was determined using the Solvita® gel system as described in Haney et al. (2008a). The Solvita gel system quantifies the relative differences in CO_2 respiration after drying and rewetting using a pH-sensitive gel paddle and digital color reader that incorporates diode array detection technology to determine the intensity of red, blue, green emission. From these direct results, several other nutrient forms were estimated (Table 1).

2.4. Analysis of plant available N and P

The raw data from each instrument is copied into a macro-enabled Excel file that uses Visual Basic to make unit conversions and calculations and organize the soil test N, P, and K results and the soil health score. The thought process and mechanics of these determinations are discussed subsequently.

Plant available N and P estimates from the Soil Health Tool include inorganic and potentially mineralizable forms. Potential N mineralization is calculated with Eq. (1).

$$N\ \ min\left(\frac{kg}{ha}\right) = MAC \times WEON \times 2.24 \times n \tag{1}$$

Where: microbially active C (MAC) is the amount of 1 day CO_2-C release (mg/kg soil) relative to active organic C (WEOC, mg/kg soil); WEON is the active organic soil N (mg/kg soil); 2.24 converts to kg/ha; and n is the number of rainfall and irrigation events (> 1 in) throughout the growing season (a value of 4 is a reasonable estimate but it can be adjusted by region). For example, 200 mg WEOC/kg soil, 20 mg WEON/kg soil, and 50 mg CO_2-C/kg from respiration results in 25% of the C in the active organic pool being released in the 24-h incubation. Therefore, 25% of the N in the organic pool (11.2 kg/ha) would also be released since organic N is mineralized by microbes in conjunction with organic C mineralization. Franzluebbers et al. (1996b) determined that the coefficient of determination (r^2) for net N mineralization after 21 days and CO_2 evolved during the first day after rewetting dried soil was 0.85 for eight soils with varying characteristics. Haney et al. (2001) found that the results from 1-day CO_2 analysis adequately represent pools of SOM readily mineralizable by the active soil microbial biomass based on relationships with laboratory N mineralization and forage N uptake.

The total plant available N available is calculated with Eq. (2).

$$plant\ \ available\ N\left(\frac{kg}{ha}\right) = NH_4N(water) \times 2.24 + NO_3N(water) \times 1.6 + N\ \ min \tag{2}$$

Where: *$NH_4N(water)$* is water extractable NH_4-N; 2.24 is the conversion factor from mg/kg soil to kg/ha; *$NO_3N(water)$* is water extractable NO_3-N; and 1.6 is the conversion factor from mg/kg soil to kg/ha assuming a 30% loss of NO_3-N to leaching and denitrification.

Potential P mineralization is calculated with Eq. (3)

$$P\ \ min\left(\frac{kg}{ha}\right) = MAC \times EOP \times 2.24 \times n \tag{3}$$

Where: *EOP* is H3A extractable organic P; 2.24 is the conversion factor from mg/kg soil to kg/ha; and *n* is the number of rainfall and irrigation events (> 2.54 cm) throughout the growing season (a value of 4 is a reasonable estimate but it can be adjusted by region).

The total plant available P available is calculated with Eq. (4).

$$plant\ \ available\ P_2O_5\left(\frac{lb}{ac}\right) = PO_4P(H3A) \times 2.3 + P\ min \tag{4}$$

Where: 2.3 is the conversion factor from kg P/ha soil to kg P_2O_5/ha.

The N and P mineralization estimates are affected by the water extractable organic C:N ratio. Research has shown that soil C:N ratio above 20:1 generally indicate that no net N and P mineralization will occur as the N and P are sequestered within the microbial cell (Tate, 1995; Bengtston et al., 2003; Haney et al., 2012). Below 20:1, as the ratio decreases, release to the soil solution increases and provides additional plant available N and P. The Soil Health Tool applies this same mechanism to the water extractable C:N ratio to adjust N and P mineralization from the organic pools, with the largest mineralization occurring between 8:1 and 15:1.

The Soil Health Tool then makes fertilizer recommendations by subtracting the total plant available N and P estimates from the crop-specific nutrient requirements for a desired yield goal. The nutrients requirements per unit production of major cash crops are well established and publically available (Table 2).

2.5. Calculation of the soil health score

The numerical soil health score for evaluating soil health in terms of

Table 1
Soil properties measured in the Soil Health Tool.

Direct measurement	Extractant	Instrument
NO_3-N, NH_4-N, PO_4-P	water	RFA colorimetric
NO_3-N, NH_4-N, PO_4-P	H3A	RFA colorimetric
water extractable organic C (WEOC)	water	C:N analyzer
total water extractable N (WEN)	water	C:N analyzer
total P	H3A	ICP
total Ca, Fe, Al, K	H3A	ICP
1 day CO_2-C	–	Solvita
inorganic N = NO_3-N + NH_4-N	H3A	–
organic N (WEON) = WEN − NO_3-N − NH_4-N	water	–
inorganic P = PO_4-P	H3A	–
organic P = total P − inorganic P	H3A	–

Table 2
Nutrients required by major cash crops (IPNI, 2014).

Crop	Unit[a]	Nutrients Required		
		N	P	K
Corn	kg nutrient per 25.4 kg shelled corn	0.45	0.10	0.19
Wheat	kg nutrient per 27.2 kg wheat	0.54	0.10	0.19
Soybeans[b]	kg nutrient per 27.2 kg soybean	1.4	0.20	0.53

[a] Weight in kg is provided and was converted from the weight of each grain/bushel as it is commonly expressed in the United States.
[b] The majority of N is fixed by the plant. No N fertilization is needed if the seeds are inoculated.

nutrient cycling is calculated with Eq. (5).

$$SHS = \frac{1\text{ day }CO_2C}{10} \times \frac{WEOC}{100} \times \frac{WEON}{10} \tag{5}$$

This calculation accounts for the general standard 10:1C:N ratio of soil and accounts for the microbial activity of the soil in representing the nutrient cycling ability of soil. It combines 5 independent measurements of soil biological and chemical properties (NH_4-N, NO_3-N, WEOC, WEN, and 1 day CO_2-C).

This soil health calculation number varies from 0 to 50 in most systems but can be as high as 100 in pastures or native grasslands. We like to see this number increase over time as management positively affects the soils biological health. The results from these analyses indicate the current soil health and what is needed to reach a more sustainable state. Monitoring the soil health score over time will allow individuals to gauge the effects of their management practices over the years.

3. Results and discussion

3.1. Corn

Many (166) corn producers provided soil samples, yields, and management practices from 18 states, the majority being from Iowa, Indiana, Minnesota, and South Dakota. Many of the producers practiced no-till, reduced tillage, or conventional till, with some of them combining more than one practice. The total area represented was 3295 ha with an average field size of 19.8 ha and an average corn yield of 10.4 MT/ha (Table 3). Total plant available nutrients averaged 66 kg N/ha, 101 kg P_2O_5/ha, and of 142 kg K_2O/ha, and 173 kg N/ha, 49 kg P_2O_5/ha, and of 57 kg K_2O/ha were applied on average. The soil fertility recommendations based on the nutrient requirements (Table 2) minus the available N, P, and K (Table 1) were lower than the average amounts applied. There was a significant but very weak relationship between the N applied and corn yield ($r^2 = 0.13$, $p < 0.001$, Fig. 1) and no relationship between \$ spent on fertilizer and corn yield ($r^2 = 0.06$, $p = 0.002$, Fig. 2). Although conventional wisdom indicates that more is better in terms of fertilizer rates, economic and environmental concern dispels this philosophy. Producers on average spent \$130 per 0.4 ha (1 ac) on fertilizers to grow corn, but expenditures > \$130/0.4 ha appear to provide no yield increase. Roughly 20% of the producers followed the fertilizer recommendations, and the majority of producers applied more N than is required based on actual yield. Corn requires 0.45 kg N/25.4 kg (1 bu) corn (Table 2), but producers applied an average of 0.58 kg N/25.4 kg corn (22% over application) based on the amount of N needed to grow the actual yield.

Table 3
Results of soil health testing by crop of soil samples collected from across the contiguous US.

	Corn	Wheat	Soybeans
Total area (ha)	3295	2304	2311
Average			
Field size (ha)	19.8	27.1	12.5
Yield (MT/ha)	10.4	3.0	3.2
N to grow 1 unit grain	1.3	2.7	1.3
Soil health score	10.0	8.6	8.8
Soil test N (kg/ha)	66.1	54.9	48.2
N applied (kg/ha)	172.5	86.2	24.6
Soil test P_2O_5 (kg/ha)	100.8	68.3	73.9
P_2O_5 applied (hg/ha)	49.3	29.1	23.5
Soil test K_2O (kg/ha)	142.2	241.9	138.9
K_2O applied (kg/ha)	57.1	7.4	33.6
\$US value of soil test NPK	\$141	\$146	\$114
\$US value of NPK applied	\$130	\$60	\$37
Producers using no-till	181	72	157
No-till average yield (MT/ha)	10.4	3.6	3.9
Producers using reduced till	34	8	21
Reduced till average yield (MT/ha)	10.9	3.5	3.4
Producers using conventional till	14	5	7
Conventional till average yield (MT/ha)	10.2	2.3	3.7
Producers using cover crops	87	29	94
Average yield cover crops (MT/ha)	10.8	3.4	3.9
Producers without cover crops	79	56	81
Average yield no cover crops (MT/ha)	10.1	3.5	3.7

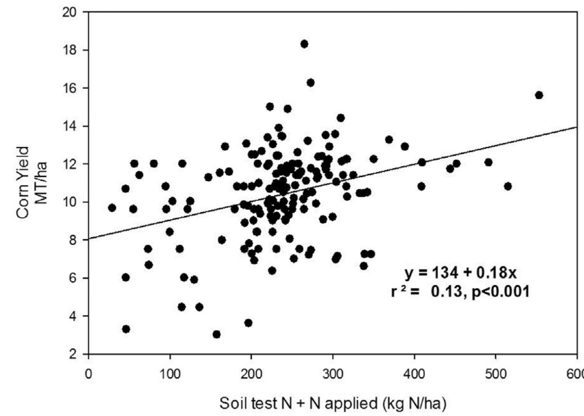

Fig. 1. Corn yield versus soil test N plus fertilizer N.

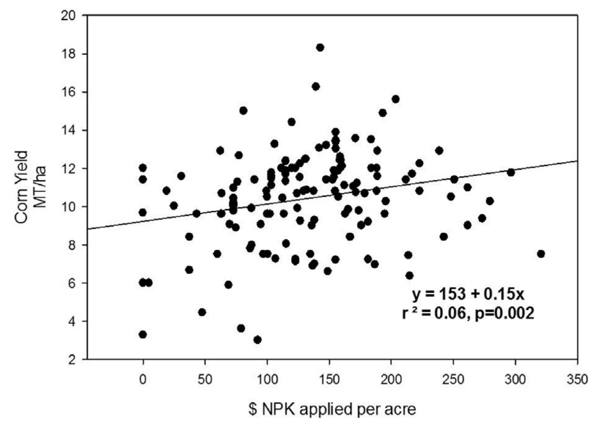

Fig. 2. Corn yield versus dollars spent on fertilizer.

The average soil health score for soils with corn production was 10 (Table 3, Fig. 3). One surprising result was that the amount of N applied did not decrease as the soil heath score increased (Fig. 3). The results also indicate that even soils with a low soil health score (data not shown) are capable of growing corn efficiently (near 1 in N/unit corn).

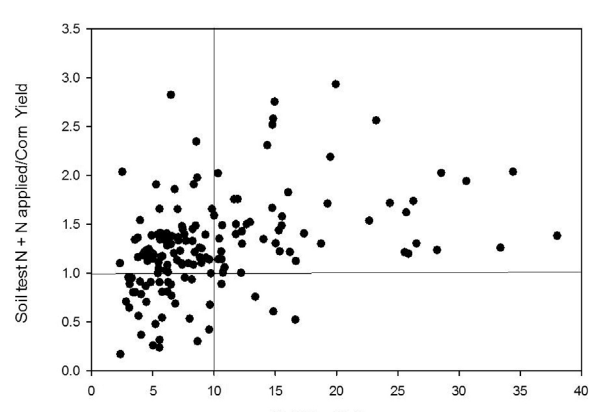

Fig. 3. Soil test N plus fertilizer N per unit of corn yield versus the soil health score.

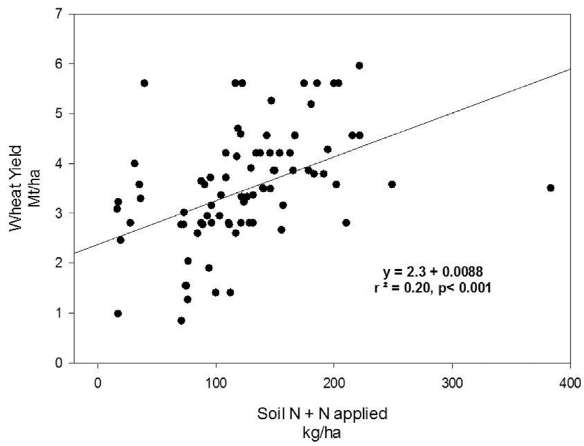

Fig. 4. Wheat yield versus soil test N plus fertilizer N.

3.2. Wheat

Producers growing Durum or Hard Red winter wheat numbered 85 from 11 states with the majority from Kansas, Montana, and North Dakota. The total area in wheat represented 2310 ha with an average field size of 27 ha with an average wheat yield of 3.0 MT/ha (Table 3). Total plant available nutrients averaged 55 kg N/ha, 68 kg P_2O_5/ha, and 242 kg K_2O/ha, and 86 kg N/ha, 29 kg P_2O_5/ha, and 7.4 kg K/ha were applied on average. No-till and reduced till appeared to produce higher average yields than conventional tillage; however, the number of producers using reduced tillage (8) and conventional tillage (5) was low compared to no-tillers (72). Similar to corn, the wheat yield data indicated a significant, but very weak relationship ($r^2 = 0.20$, $p < 0.001$) between yield and N applied plus plant available N in the soil (Fig. 4). In other words, increasing fertilizer applications did not result in increased yields. Similarly, there was no significant relationship ($r^2 = 0.08$, $p = 0.042$) between yield and $ spent on N, P, and K fertilizer (Fig. 5). Producers used an average of 1.2 kg N/27 kg wheat, which is 35% more than required. Twenty-two of the 85 wheat producers were able to produce wheat with less than 2.2 kg N/ha (Fig. 6); however, the remaining 69% of producers applied more N than needed, which likely reduced profit and increased adverse environmental impact.

The soil health score for soils with wheat production averaged 8.6. As shown in Fig. 6, most of these producers could reduce fertilizer application because their soils are capable to providing much of the N needed for wheat production.

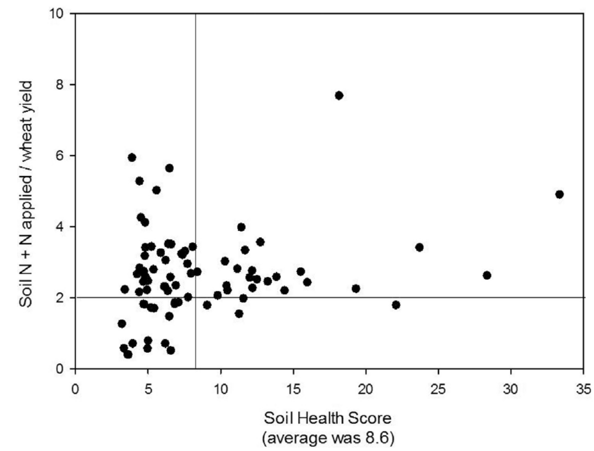

Fig. 6. Soil test N plus fertilizer N per unit of wheat yield versus the soil health score.

3.3. Soybean

One hundred eighty-five soybean producers participated in the study and represented 2311 ha of soybean land with an average field size of 12.5 ha. Plant available nutrients averaged 48 kg N/ha, 74 kg P_2O_5/ha, and 139 kg K_2O/ha, and 25 kg N/ha, 24 kg P_2O_5/ha, and 34 kg K/ha were applied on average. In contrast to corn and wheat production, P and K are generally the limiting nutrients for soybean production. In spite of this difference, there was no significant relationship ($p = 0.362$) between soybean yield and $ spent on N, P, and K fertilizer (Fig. 7). Soybean producers used an average of 0.81 kg P_2O_5/27.2 kg (bu) soybean, and 117 of 185 (63%) producers used more than 0.45 kg P_2O_5/27.2 kg soybean (Fig. 7). Many of the fields had adequate soil P levels, thus P application was unnecessary. By accounting for this important source of plant available P many soybean producers could reduce P application and maintain yields, thus increasing profit and decreasing environmental impact. These results suggest that soybean is more efficient at using N, P, and K than corn or wheat, although there is still room for improvement.

The average soil health score for a total of growing soybeans was 8.8. Fields with higher soil health scores especially those > 8.8 could likely reduce P application and rely on the soil microbes to mineralize adequate N and P to support profitable soybean production. As shown in Fig. 8, many soybean producers (53%) did not apply fertilizer but still produced yields similar to fertilized fields.

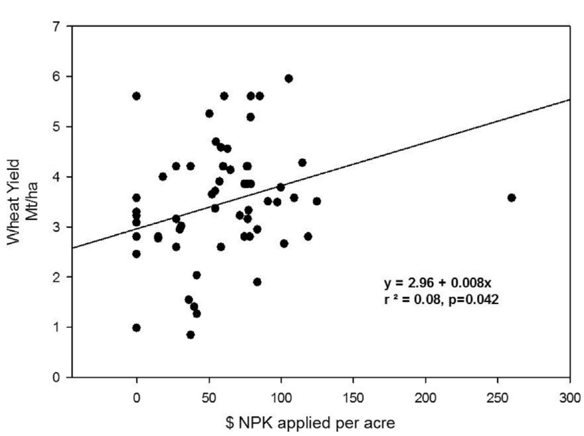

Fig. 5. Wheat yield versus dollars spent on fertilizer.

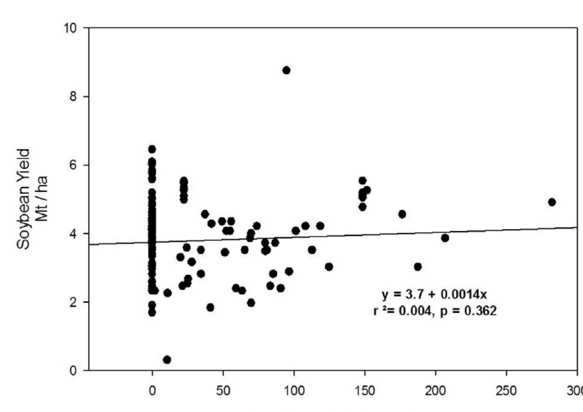

Fig. 7. Soybean yield versus dollars spent on fertilizer.

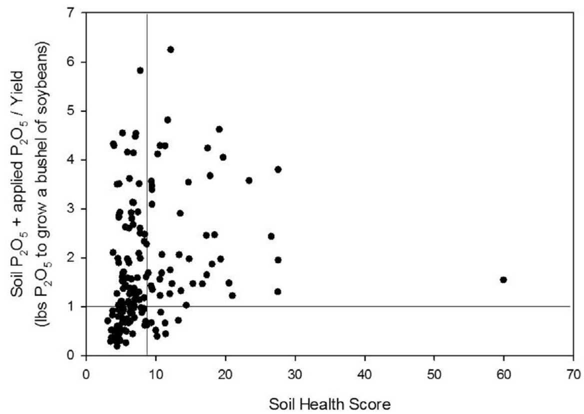

Fig. 8. Soil test N plus fertilizer N per unit of soybean yield versus the soil health score.

4. Conclusions

The Soil Health Tool is the product of 15 yr of research and development with the goal of providing a quantitative, yet simple, soil chemical and biological analytical method for soil testing laboratories quality tools to accurately estimate plant available nutrients, make defensible fertilizer recommendations, and assess the nutrient cycling ability of soils. Numerous commercial soil testing laboratories have adopted the Soil Health Tool, and collaboration with these laboratories is underway to assess the approach and make it more widely available both nationally and internationally.

Data from 26 states used in this initial broad-scale application indicate that regardless of the soil health score or soil test nutrient data, a substantial number of producers are applying more fertilizer than necessary. In another field-scale production level evaluation, Harmel and Haney (2013) showed that reductions in fertilizer application rates based on the Soil Health Test produced minimal reduction in yield and an overall increase in profitability. In only 6% of the comparisons in that study was the traditional fertilizer rate the most profitable. Certainly an increasing number of producers are more cognizant of fertilizer application rates because of increasing input costs and public scrutiny, but most would agree that further improvement is needed.

While this study, and the previous study of Harmel and Haney (2013) only represent ~500 field years of data; they represent actual production fields. It is at the field scale, versus the small plot research scale, that farmers make management decisions that ultimately determine the economic and environmental sustainability of their operation. Additional testing at the national scale on both producer fields and small research plot will further strengthen the tool by: 1) assessing regional differences, 2) better understanding soil nutrient cycling, and 3) more robust accounting for the contribution of plant available nutrients by mineralization, irrigation water, nutrients deeper in the soil profile, and organic and inorganic fertilizers. The additional analyses include data collected in 2015 and 2016. Concurrently, collaboration with the USDA Natural Resources Conservation Service (USDA-NRCS) National Soil Health and Sustainability Team is providing technology transfer and training to improve the understanding of soil health by producers, farm groups, and USDA-NRCS and USDA-ARS. Soil quality assessment tools developed through research at the USDA-ARS are currently being incorporated into the greater soil health initiative with the NRCS.

We hope that developments associated with the Soil Health Tool will help bring a greater appreciation for microbiological soil nutrient cycling to soil testing laboratories and researchers; therefore, we have made all software freely available, presented all methods in refereed journals, and are willing to share hardware designs. More importantly, however, we hope that the Soil Health Tool contributes to increasing fertilizer use efficiencies through accurate determination of plant available nutrients by soil testing laboratories and appropriate fertilizer application rates. Because it is these improvements will ultimately benefit the environment through decreased nutrient losses to the atmosphere and water resources and that will benefit the farmers and ranchers that we rely upon to feed the world.

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