RESEARCH BRIEF

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Evaluation of the Haney Soil Health Tool for corn nitrogen recommendations across eight Midwest states

M.A. Yost, K.S. Veum, N.R. Kitchen, J.E. Sawyer, J.J. Camberato, P.R. Carter, R.B. Ferguson, F.G. Fernández, D.W. Franzen, C.A. Laboski, and E.D. Nafziger

Abstract: Use and development of soil biological tests for estimating soil nitrogen (N) availability and subsequently corn (*Zea mays* L.) fertilizer N recommendations is garnering considerable interest. The objective of this research was to evaluate relationships between the Haney Soil Health Test (HSHT), also known as the Soil Health Tool or Haney test, and the economically optimum N rate (EONR) for corn grain yield at 17 sites in eight Midwest US states in 2016. Trials were conducted with a standard set of protocols that included a nonfertilized control plus six N rates applied at planting or as a split between planting and sidedress, soil samples for the HSHT prior to planting, and grain harvest at physiological maturity, and determination of EONR for each N application timing. Results indicated that HSHT recommendations with expected yield accounted for ≤28% of the variation in EONR among sites and N timings. Two components of the HSHT not directly used in the HSHT N recommendation for corn, the soil health calculation, or soil health score, and the Solvita carbon dioxide (CO_2)-Burst lab test, accounted for the most variation in EONR. These two components were moderately related (R^2 = 0.29 to 0.39) to soil organic matter (OM), highly related (R^2 = 0.98) with each other, and subsequently both accounted for over one-half (R^2 = 0.55) of the variation in EONR for N applied at planting or as a split. With additional research, these two components may help improve N recommendations for corn in the Midwest, especially Solvita CO_2-Burst because it costs less to determine than the soil health calculation.

Key words: economic optimum nitrogen rate—Haney test—nitrogen timing—soil health calculation—soil health nutrient tool—Solvita CO_2-Burst

Understanding and accounting for the influence of soil microbial activity on soil nutrient availability has potential to assist with optimizing fertilizer management. A recently commercialized and evolving soil test that includes measures of soil biological activity is the Haney Soil Health Test (HSHT). The test is also commonly referred to as the Soil Health Tool (Woods End Laboratories, Mt Vernon, Maine) or the Haney test (Ward Laboratories, Kearney, Nebraska). The HSHT seeks to incorporate both soil chemistry and biology into decision making tools for soil health assessment and scoring, plant available nutrient levels, and fertilizer rate recommendations. Midwestern US growers are particularly interested in how the HSHT might improve nitrogen (N) fertilizer management for high-N demanding crops like corn (*Zea mays* L.). The major components of the tool for N include the rapid (24 hour) burst, or flush, of carbon dioxide (CO_2) following rewetting of dry soil (i.e., Solvita CO_2-Burst), water extraction of N and organic C, and the weak acid (Haney, Haney, Hossner, Arnold [H3A]) extraction of inorganic N (Franzluebbers et al. 1996; Doran et al. 1997; Haney and Haney 2010; Haney et al. 2012, 2015). From these components, a soil health calculation, or soil health score, and plant available N calculation are derived. The HSHT N rate recommendation for corn and other crops is the plant available N calculation subtracted from expected yield recommendations that are calculated using a fixed amount of N fertilizer per unit of yield. Nitrogen rates based on yield expectations often do not relate well to economically optimum N rate (EONR) because corn yield level and N fertilizer requirements are independent in many parts of the Midwest (Sawyer et al. 2006), but the plant available N calculation or other components of the HSHT might relate to the N fertilizer needs of corn.

The Solvita CO_2-Burst is a major component of the soil health and plant available N calculations, and subsequently N fertilizer recommendations produced from the HSHT. Calibration of the CO_2-Burst to N availability in the field has been identified as a critical need for biological soil testing development (Franzluebbers 2016). Most of the effort to this end has focused on relationships between the CO_2-Burst and plant N uptake in the absence of fertilizer, and results on a range of soils have shown moderate to strong relationships (R^2 > 0.76) between the two (Haney et al. 2001; Franzluebbers 2016; Pershing 2016). Other recent field trials in Texas have shown that the HSHT generally recommended less N but maintained profit compared to traditional grower rates (Harmel and Haney 2013). However, few, if any, reports have determined the relationships between the HSHT recommendations or components (i.e., plant available N calculation, soil health calculation, and Solvita CO_2-Burst) and the optimal amount of fertilizer required for a given crop—thus creating a crucial void concerning the value of the HSHT to refine fertilizer N rate guidelines. Therefore, the primary objective of this research was to determine whether N recommendations based on the HSHT or

Matt A. Yost (corresponding author), **Kristen S. Veum**, and **Newell R. Kitchen** are research soil scientists with the USDA Agricultural Research Service (ARS) Cropping Systems and Water Quality Research Unit in Columbia, Missouri. **John E. Sawyer** is a professor with Iowa State University in Ames, Iowa. **James J. Camberato** is a professor of agronomy at Purdue University in West Lafayette, Indiana. **Paul R. Carter** is a senior agronomy services manager at DuPont Pioneer in Johnston, Iowa. **Richard B. Ferguson** is a professor at the University of Nebraska in Lincoln, Nebraska. **Fabián G. Fernández** is an associate professor with the University of Minnesota in St. Paul, Minnesota. **David W. Franzen** is an extension soil specialist with North Dakota State University in Fargo, North Dakota. **Carrie A. Laboski** is a professor with the University of Wisconsin in Madison, Wisconsin. **Emerson D. Nafziger** is a professor with the University of Illinois at Urbana-Champaign, Illinois.

components of the HSHT relate to EONR for corn grown across a wide range of soils and weather conditions in the midwestern United States. A secondary objective was to examine relationships between soil organic matter (OM) and other components of the HSHT to determine what additional information the HSHT might offer.

Materials and Methods

Soil samples were collected from 17 corn N response trials in eight states in the midwestern United States. Each trial was established and managed according to a common protocol (Kitchen et al. 2017). Nitrogen fertilizer was broadcast-applied by hand as ammonium nitrate (NH_4NO_3) at planting at rates ranging from 0 to 270 kg N ha^{-1} in 45 kg N ha^{-1} increments or as a split application with 45 kg N ha^{-1} at planting and 45 to 225 kg N ha^{-1} as a sidedress at V9. Each treatment was replicated four times in each trial. When needed (low- or medium-testing soil), broadcast phosphorus (P), potassium (K), and sulfur (S) were applied in the early spring according to soil test results and university guidelines in each state. Pertinent site details are included in table 1. Grain yield was measured at physiological maturity, and N response functions were derived by N application timing using the REG and NLIN procedures of SAS (SAS Institute 2009) to select the significant ($p \leq 0.05$) regression model (quadratic-plateau or quadratic) with the greatest correlation coefficient. The first derivatives of the best-fit regressions were set to a common N fertilizer:corn grain price ratio of US\$0.0056 kg^{-1} N:US\$ Mg^{-1} grain to estimate EONR. Nitrogen applied across all fertilizer N treatments as starter and/or with irrigation at 6 of 17 sites was added to calculated EONRs. All regressions between the HSHT and EONR were also conducted for EONR without starter or irrigation N added, but the results were similar (R^2 changed by ≤0.09), so only EONR with added N is presented. Similarly, regressions between HSHT and the agronomic optimum N rate were evaluated and were similar to relationships between HSHT and EONR (R^2 were 0.02 to 0.04 greater for the three HSHT recommendations compared to agronomic optimum N rate than EONR, but were 0.06 to 0.10 less for the three HSHT components).

In the spring of 2016 prior to corn planting, eight 32 mm diameter soil cores were collected to 15 cm depth and composited into one sample per replicate. Samples were dried in a forced-air oven at 50°C for 48 hours, ground to pass a 2 mm sieve, and analyzed for the HSHT at a commercial soil testing laboratory (Ward Laboratories, Kearney, Nebraska). The CO_2-Burst was determined by adding 25 mL of deionized water to 40 g of dry soil inside a 0.24 L glass jar, inserting a Solvita detector probe and capping the jar, and removing the probe after 24 hours of incubation (Haney et al. 2015). Probes were then inserted into a Solvita Digital Color Reader (Woods End Laboratories, Mt Vernon, Maine).

Plant available N was calculated as

$$\text{H3A extractable } NO_3\text{-N} + \text{H3A extractable } NH_4\text{-N} + \text{N release}, \text{ where} \quad (1)$$

$$\text{N release} = \text{Nmin} + \text{MAC\_WEON},$$

$$\text{Nmin} = CO_2\text{-Burst} \times \{[(-0.068 \times \text{WEOC:N}) + (0.00095 \times \text{WEOC:N}^2) + 0.97] / 2\}, \text{ and}$$

$$\text{MAC\_WEON} = \text{WEON} \times (CO_2\text{-Burst} / \text{WEOC}),$$

where Nmin is N mineralization, MAC_WEON is microbially active water extractable organic N, and WEOC:N is water extractable organic C:N ratio.

The Nmin was considered zero if WEOC:N was greater than 40. If N release was greater than WEON, then N release was set equal to WEON. Plant available N concentration was multiplied by an assumed bulk density of 1.3 g cm^3 as a part of standard procedures for the HSHT.

The soil health calculation was calculated using equation 2:

$$[(CO_2\text{-Burst} / \text{WEOC:N}) + (\text{WEOC} / 100) + (\text{WEON} / 10)]. \quad (2)$$

The HSHT N fertilizer recommendation was calculated as

$$(\text{expected grain yield} \times 0.45 \text{ kg N}^{-1}/25 \text{ kg}^{-1} \text{ yield}) - \text{plant available N} - \text{irrigation N} - \text{other applied N}, \quad (3)$$

where expected grain yield, plant available N, irrigation N, and other applied N are in kg ha^{-1}.

Other versions of these equations exist, but the equations presented here were those used as of May 5, 2017, by Ward Laboratories (Kearney, Nebraska). The coefficent of variability (CV) in plant available N, soil health calculation, and the Solvita CO_2-Burst was calculated across reps by site as the standard deviation divided by the mean. The mean CV across sites of the three HSHT components were compared using the PDIFF option of the MIXED procedure of SAS.

Two methods for determining yield expectation were evaluated. The first expected grain yield level was based on recent yield history of the field where the experiment was conducted. Yield history was not available for some of the sites on commercial farms, so yield expectation was determined by consulting with the cooperating grower and local agronomists to obtain an average yield history of nearby fields. The second was a systematic approach that used historical county average grain yield (2011 to 2015) for the county where the site was located multiplied by 110%, 120%, and 130% for low, medium, and high productivity soil, respectively, where soil productivity was defined similarly to Laboski and Peters (2012) and Shapiro (2008). A third evaluation used the measured yield at the plateau of the quadratic-plateau regression model. The purpose of this last scenario was to evaluate how the HSHT N recommendation performed if yield level could be predicted at planting.

The three N recommendations of the HSHT and three components of the HSHT were compared to EONR using the REG procedure of SAS at $p \leq 0.05$. Linear and quadratic regressions were evaluated for each dependent variable, and the selected model was significant and had the greatest correlation coefficient. All other linear regressions were conducted using the same methods. The influence of N timing on relationships between HSHT and EONR was tested using the GLM procedure of SAS at $p \leq 0.05$.

Results and Discussion

The yield increase with N (i.e., delta yield) ranged from 0 to 11.7 Mg ha^{-1} among N timings and sites with agronomic optimum N rates ranging from 0 to 334 kg N ha^{-1} and EONR from 0 to 313 kg N ha^{-1} (table 1). The EONR with a split application was greater than the at-planting EONR at 6 of 17 sites. Two of these six had differences less than 5 kg N ha^{-1}. Larger differences of up to 100 kg N ha^{-1} greater EONR with split application at the remaining four site-years suggest that N stress may have occurred before sidedress N application.

Table 1

Site characteristics, economically optimum nitrogen (N) rate (EONR), three Haney Soil Health Test (HSHT) N recommendations, and mean and standard deviation (in parentheses) of HSHT components for 17 sites in eight Midwest states in 2016.

				Delta yield		EONR§		HSHT N recommendation‖				HSHT components#		
State	Site*	Text.†	OM (g kg^{-1})‡	AP (Mg ha^{-1})	SP (Mg ha^{-1})	AP (kg N ha^{-1})	SP (kg N ha^{-1})	1 (kg N ha^{-1})	2 (kg N ha^{-1})	3 (AP) (kg N ha^{-1})	3 (SP) (kg N ha^{-1})	PAN (kg N ha^{-1})	SHC	CO_2-Burst (mg CO_2-C kg^{-1})
Iowa	Crawfordville	scl	42	4.51	7.02	90	190	164	200	156	204	56 (6)	7.5 (1.6)	46 (22)
	Story	cl	37	8.07	7.77	186	188	180	193	223	220	56 (15)	7.6 (0.5)	49 (1)
Illinois	Shumway	sil	24	7.09	5.02	228	164	140	151	188	153	62 (11)	6.6 (0.7)	46 (4)
	Urbana	sil	37	7.49	7.57	205	177	183	190	198	197	63 (10)	8.4 (1.2)	59 (16)
Indiana	Loam	l	52	8.16	7.85	162	151	152	161	209	203	61 (12)	9.5 (1.4)	65 (19)
	Sand	sl	22	5.51	5.31	132	119	132	156	219	215	58 (6)	5.7 (0.2)	31 (3)
Minnesota	Becker	ls	21	7.33	11.74	268	313	168	138	129	200	28 (4)	3.5 (0.2)	16 (4)
	Waseca	cl	54	8.11	7.53	234	167	159	174	212	197	64 (12)	9.6 (1.3)	70 (22)
Missouri	Bradford	sil	25	5.92	6.78	164	191	105	94	162	177	63 (9)	7.0 (2.5)	46 (25)
	Loess	sil	32	7.33	6.81	239	205	148	129	213	204	75 (12)	8.4 (2.3)	55 (26)
	Troth	sicl	33	7.74	6.49	258	207	197	121	214	190	49 (4)	6.3 (0.1)	32 (5)
North Dakota	Amenia	sil	39	0	0	45	45	111	76	87	88	68 (7)	8.1 (1.3)	60 (16)
	Durbin	c	49	0	0	0	0	91	77	61	61	111 (25)	18.8 (1.2)	150 (11)
Nebraska	Kyes	l	25	5.80	6.44	208	186	129	173	213	221	54 (5)	7.4 (0.4)	36 (4)
	SCAL	sil	34	1.59	1.57	70	70	175	182	183	183	60 (7)	13.7 (2.4)	93 (13)
Wisconsin	Lorenzo	sil	53	1.95	2.05	73	78	117	142	111	113	90 (16)	14.6 (0.9)	113 (10)
	Plano	sil	44	1.35	2.53	106	143	173	178	177	195	73 (13)	10.1 (1.6)	77 (17)

*All sites had tillage, except for both sites in Nebraska and Wisconsin, and Troth in Missouri. The crop prior to corn was soybean at all sites except Durbin and SCAL, which were sunflower and corn, respectively.

†Text. = soil textural class. c = clay. cl = clay loam. l = loam. ls = loamy sand. sl = sandy loam. sicl = silty clay loam. sil = silt loam.

‡OM = organic matter measured by loss-on-ignition in top 15 cm of soil prior to planting.

§EONR at price ratio of 0.0056 US$ kg^{-1} N/US$ Mg^{-1} grain (0.10 US$ lb^{-1} N/US$ bu^{-1} grain) for N applied at planting (AP) or as split (SP) between AP and sidedress. Additional N applied (in the prior fall, 12 kg N ha^{-1} at SCAL; as starter, 7 kg N ha^{-1} at Kyes or SCAL; or with irrigation, 28, <1, 23, or 14 kg N ha^{-1} at Becker, Troth, Kyes, or SCAL, respectively) was added to the calculated EONR. At the Amenia site, there was no response to N treatments, but 45 kg N ha^{-1} was errantly applied in June in all plots so the precise EONR could not be determined and would be ≤45 kg N ha^{-1}.

‖Three HSHT recommendations, based on two expected yield levels or measured yield for N applied at AP or SP. The additional N mentioned in the footnote above was subtracted from HSHT recommendations.

#PAN = plant available N. SHC = soil health calculation.

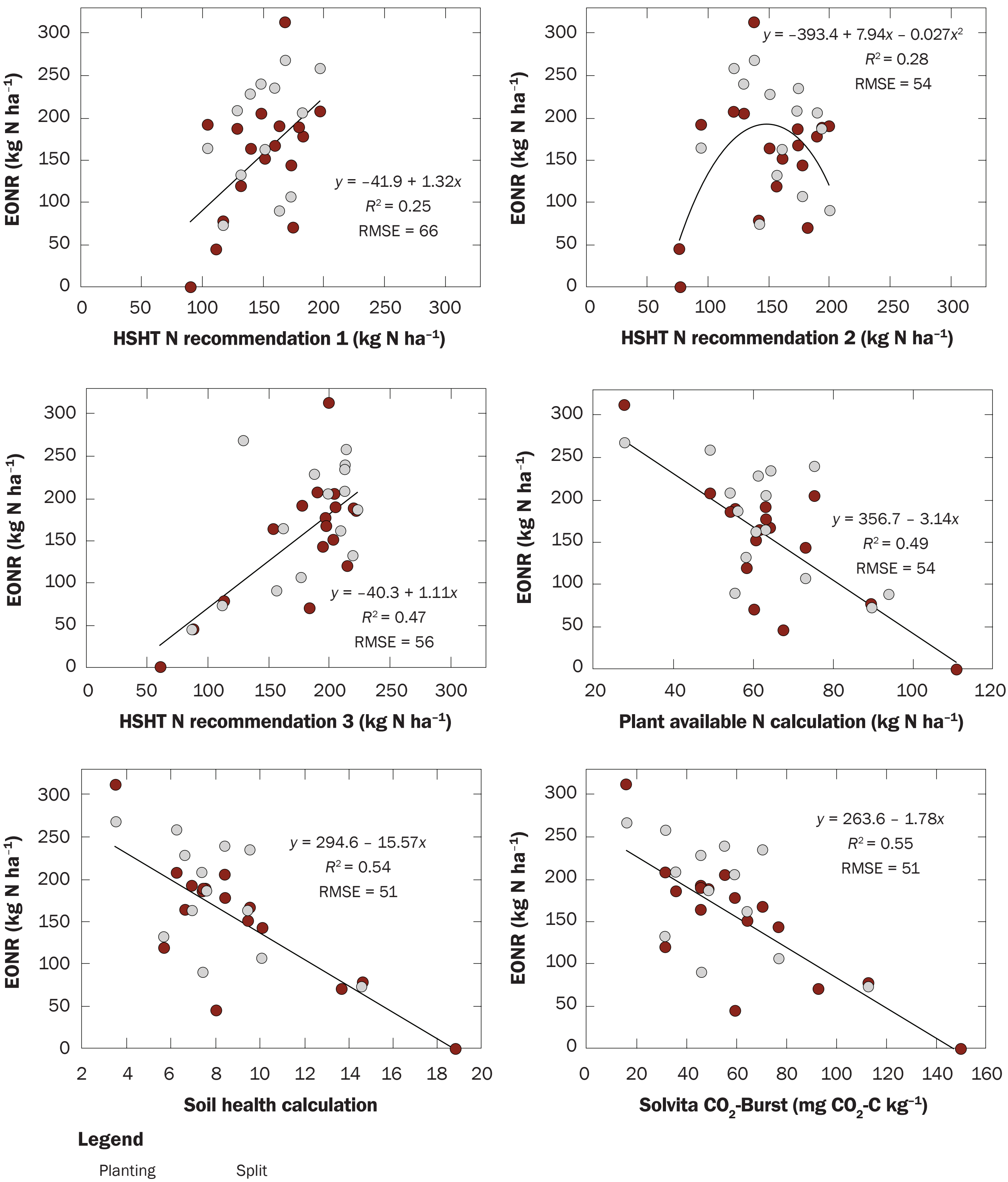
Corn grain yield at the two expected levels (recent yield history versus county yield with productivity adjustment) did not relate well to each other ($p = 0.027$; $R^2 = 0.26$), and only the second yield estimation approach that used the productivity adjustment was somewhat related to measured yield ($p = 0.004$; $R^2 = 0.20$). The two N recommendations from the HSHT based on expected yield explained up to a maximum of 28% of the variation in EONR (figure 1). The HSHT using county-based expected yield with the productivity adjustment accounted for only slightly more variation in EONR across N timings ($R^2 = 0.28$ versus 0.25) than the HSHT utilizing the yield history of the field. These results confirm previous reports that the use of expected yield level has limited utility in fertilizer N recommendations or guidelines for corn grown in much of the Midwest (Sawyer et al. 2006). Furthermore, yield expectations based on recent yield history did not improve recommendations. When measured yield was used, modest improvements were realized: the N recommendation from the HSHT accounted for 47% of the variation in EONR across N timings.

The unique aspect of the HSHT N recommendation, in relation to historical recommendations based solely on expected yield or expected yield plus soil NO_3-N, is the subtraction of the plant available N calculation that includes inorganic N and estimates of mineralizable N. The HSHT plant available N calculation ranged from 28 to 111 kg N ha^{-1} across sites (table 1) and did not vary widely among replicates as evidenced by CV in plant available N across replicates ranging from 7% to 28% (mean = 15%). Plant available N accounted for a similar amount of variation (49% versus 47%) in EONR as the HSNT recommendation based on measured yield (figure 1). Thus, the plant available N portion of the HSHT recommendation could potentially be used with other factors to better estimate EONR for corn in the Midwest.

The soil health calculation, which is not used in HSHT N recommendation, ranged from 4 to 19 across sites (table 1) and explained more variation in EONR across N timings than the three yield-based HSHT N recommendations or plant available N (figure 1). In addition to accounting for more variation in EONR, the soil health calculation had equivalent variation ($p = 0.55$) among replicates and across sites (CV = 13%) as plant available N. Nearly all of the variation ($R^2 = 0.98$) in the soil health calculation was explained by one part of the calculation, Solvita CO_2-Burst. The CO_2-Burst alone explained the most variation in EONR and also explained

Figure 1

Relationships between the Haney Soil Health Test (HSHT) nitrogen (N) recommendations for corn using two different expected yield levels (yield history or adjusted county yield) and site-measured yield, plant available N calculation, soil health calculation, and Solvita carbon dioxide (CO_2)-Burst from HSHT results and the economically optimum N rate (EONR) for corn for N applied at planting or as a split at 17 sites in eight Midwest states in 2016. RMSE is root mean square error of EONR in kg N ha^{-1}. Within dependent variables, intercepts and slopes of regressions lines did not differ between N timings ($p > 0.88$), so a single regression was conducted across timings. All regressions were significant at $p \leq 0.002$.



much of the variation in the plant available N calculation (R^2 = 0.80). The coefficient of determination between CO_2-Burst and EONR indicated that it may have value in helping to determine the EONR for corn. However, the CO_2-Burst spatial variation was greater than the other two HSHT parameters (mean CV across replicates and sites was 23% [3% to 54%]; p = 0.013), indicating it may require more intensive sampling than other components of the HSHT.

The CO_2-Burst coefficients of determination with EONR across N timings improved by only 2% points when the two sites with low OM and the most coarse-texture (Becker and Sand; table 1) were omitted. This scenario was evaluated because the CO_2-Burst can be underestimated when a fixed volume of water is used for the test instead of wetting to 50% water-filled pore space (Tu et al. 2015). Future work should examine whether the correlation of CO_2-Burst to EONR would be strengthened by measuring the burst, or flush, of CO_2 after 72 hours instead of 24 hours (Franzluebbers et al. 2000), collecting samples just before sidedressing instead of at planting for split applications, and/or by accounting for soil texture.

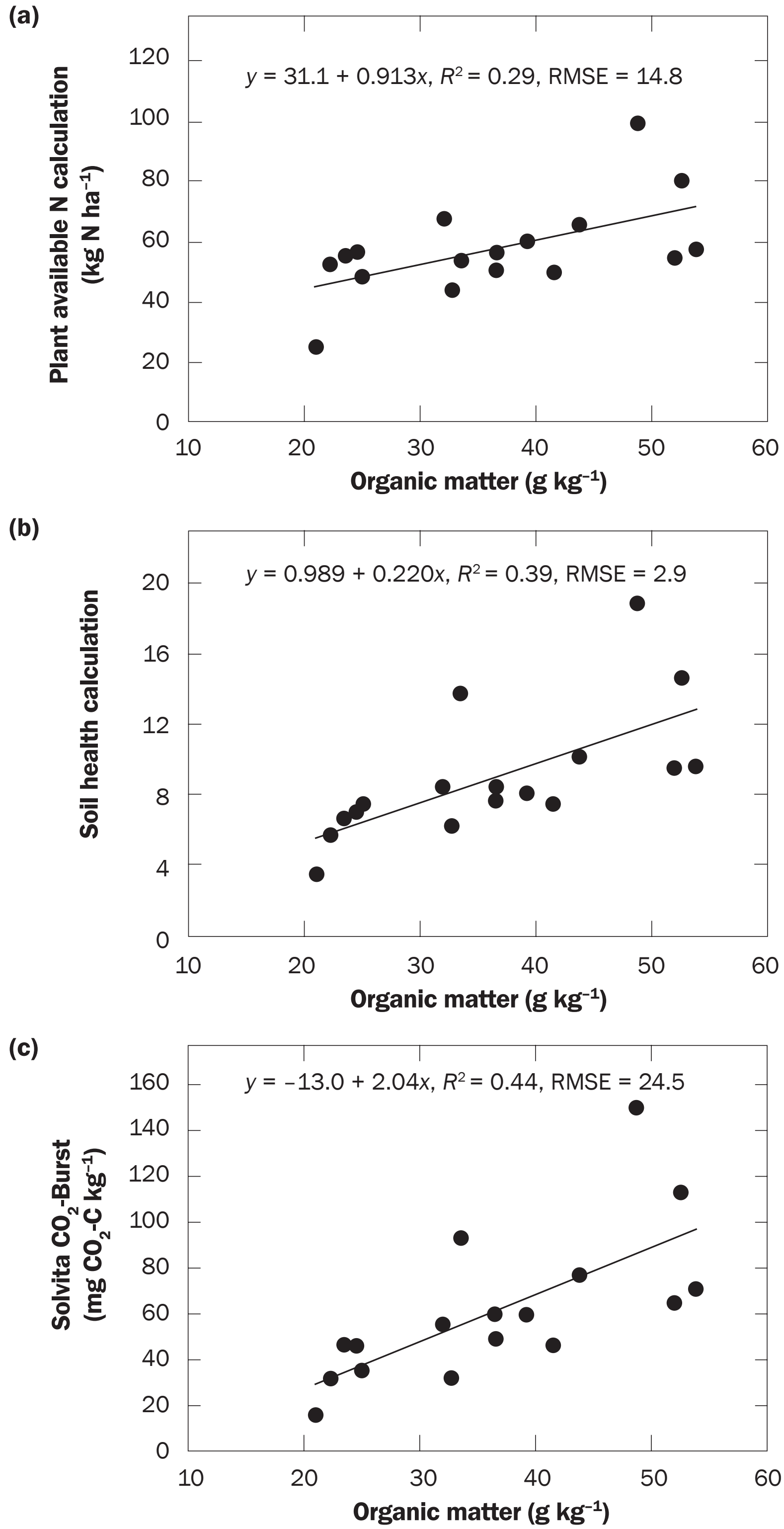
Soil OM was moderately related (R^2 = 0.29 to 0.44) to all three HSHT components (figure 2). The best relationship was between OM and Solvita CO_2-Burst (R^2 = 0.44), and it was similar to the relationships in previous reports from Minnesota and New York across soil textural classes (R^2 = 0.42 to 0.55) (Tu et al. 2015; Sadeghpour et al. 2016). Although there was a moderate relationship between these two variables, OM alone only accounted for 18% of the variation in EONR across N timings (EONR = 270.6 to 31.8 OM; p = 0.0067), indicating that Solvita may add value beyond routine OM in estimating the EONR of corn.

Summary and Conclusions

Three N recommendations (two based on different expected yields and one with measured yield) and three components of the HSHT (plant available N, soil health calculation, and Solvita CO_2-Burst) were each correlated to the EONR of corn grain yield at 17 sites in eight Midwest states. These relationships were not influenced by N timing. The two N recommendations of the HSHT using expected yield did not relate well to EONR ($R^2 \leq 0.28$) across N timings. The poor correlation was mainly due to the

Figure 2

Relationships between soil organic matter concentration and selected Haney Soil Health Test (HSHT) components: (a) plant available nitrogen (N), (b) soil health calculation, and (c) Solvita carbon dioxide (CO_2)-Burst at 17 sites in eight Midwest states in 2016. RMSE is root mean square error in y-axis variable. All regressions were significant at $p \leq 0.015$.



expected yield portion of the recommendation; the plant available N calculation alone was as or more correlated to EONR. Using measured yield in the HSHT recommendation improved its correlation with EONR across N timings, but it is impossible to know actual yield before fertilizer needs to be applied. The CO_2-Burst alone explained as much or more variation in EONR as plant available N, the soil health calculation, the three HSHT N recommendations, or soil OM. It also had the lowest root mean square error of 51 kg N ha^{-1} for EONR estimation across N timings. Hence, the CO_2-Burst itself may be more valuable for assisting in improved estimation of EONR for corn in the Midwest than other aspects of the HSHT, but these results need to be independently investigated to determine their reliability over more environments.

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