CrossMark

ORIGINAL ARTICLE

Agronomic effectiveness of an organically enhanced nitrogen fertilizer

John H. Winings · Xinhua Yin · Sampson Agyin-Birikorang · Upendra Singh · Joaquin Sanabria · Hubert J. Savoy · Fred L. Allen · Arnold M. Saxton

Abstract With tighter environmental regulations and increasing energy costs over time, approaches to minimize losses from commercially available nitrogen (N) fertilizers have become more critical in recent times. An organically enhanced N fertilizer (OENF), manufactured from organic additives extracted from sterilized biosolids plus ammonium sulfate, was evaluated as an alternative N source relative to commercially available N sources, namely, ammonium sulfate and urea. The formulation was tested on corn in 2012 and 2013 at Jackson and Ames, Tennessee, under no-till and plow lands, respectively. Chemically OENF contains 14.9% N, 4.3% P_2O_5, 18.1% S, 0.6% Fe, and 3.3% OC. The N fertilizer sources were applied at N rates of 0, 85, 128, and 170 kg ha^{-1}. The P, K, and Zn nutrients were adequately supplied. The OENF and ammonium sulfate produced plant biomass significantly greater than that of urea at N rates of ≥ 85 kg ha^{-1}. Despite the fact that less P was supplied to the OENF treatments (36% less P), grain yields from the OENF were similar to those from both ammonium sulfate and urea at N rate of ≤ 128 kg N ha^{-1}, but significantly greater than those from urea at 170 kg N ha^{-1}. The fertilizer type used did not have any significant effects on disease and physical damage to the corn ears at any application rate tested. The OENF could be an alternative N source for crop production and may provide all or some of the P needs for corn production. Therefore, with additional environment benefits of encouraging recycling of municipal and domestic waste and as sources of N, P, S, Fe and organic matter, the use of OENF should be incorporated in various corn production systems.

Keywords Biosolids · Municipal waste · No-till farming · Plant biomass · Yield components · Corn

J. H. Winings · X. Yin (✉) · F. L. Allen
Department of Plant Sciences, University of Tennessee, 605 Airways Boulevard, Jackson, TN 38301, USA
e-mail: xyin2@utk.edu

S. Agyin-Birikorang · U. Singh · J. Sanabria
Soil and Plant Nutrition Division, Office of Programs, International Fertilizer Development Center (IFDC), P.O. Box 2040, Muscle Shoals, AL 35662, USA

H. J. Savoy
Department of Biosystems Engineering and Soil Science, University of Tennessee, 2506 E.J. Chapman Drive, Knoxville, TN 37996, USA

A. M. Saxton
Department of Animal Science, University of Tennessee, 2506 River Drive, Knoxville, TN 37996, USA

Introduction

Nitrogen is one of the most essential plant nutrients because it plays numerous important biochemical and physiological roles in the growth and development of all plants. As a result, N needs to be supplied adequately to ensure proper growth and development

Springer

of crops. Furthermore, in contrast to most other plant nutrients, soil N is subject to many transformations and losses thereby limiting crop production (Robertson and Vitosek 2009). This dynamic nature of N has made its management one of the most difficult challenges in modern agriculture (Binder et al. 2002). Since no farm can be reasonably expected to raise high yielding crops without providing the necessary amounts of plant nutrients, particularly N, fertilizer expenses are one of the greatest variable costs to any successful farm operation (Economic Research Service 2013).

Increasing amounts of N application to agricultural land has historically been done with inorganic fertilizers since the inception of the Green Revolution (Jenkinson 2001) and has continued till present. However, with tighter environmental regulations and increasing energy costs over time, approaches to minimize soil N losses have become more critical in recent times. Urea and ammonium sulfate are two most commonly used N fertilizers globally. A new and alternative N fertilizer that is under development is an organically enhanced N fertilizer (OENF), which is manufactured by using sterilized and chemically converted organic materials extracted from municipal wastewater biosolids. The OENF was manufactured using a patented and proprietary process that uses sterilized organic material extracted from municipal wastewater sludge and/or manures to form additives (NSF 2010). This formulation holds a lot of promise in terms of minimizing losses associated with the conventional N fertilizers (NSF 2010; Singh et al. 2012). Thus, OENF has the potential to increase agronomic effectiveness of applied N, and consequently make an important contribution toward environmental sustainability. Singh et al. (2012) showed through incubation studies that there was a slower nitrate formation in soils amended with OENF s compared to urea, due to significantly longer lag phase duration. The delayed nitrification rate could result in better matching between N supply and N demand by crops and reduced nitrate N losses. Further, the authors showed that OENF had significantly lower NH_3–N volatilization losses and NO_3^-–N leaching losses (Singh et al. 2012). These attributes of OENF could potentially lead to increased N use efficiency, resulting in increased N savings, and less negative environmental emissions.

In spite of these observations, to date, no field studies have been conducted to validate the conclusions from the laboratory studies of Singh et al. (2012). Thus, based on the results of the studies from Singh et al. (2012), we hypothesized that OENF will improve corn growth and yields relative to the conventional fertilizers. The overall objective of this investigation was therefore to evaluate the agronomic effectiveness of OENF. Specific objectives were to compare the effectiveness of OENF to the commonly used commercial N fertilizers, urea and ammonium sulfate, in terms of improving plant growth, grain yield, and ear health of corn with a systems approach.

Materials and methods

Prior to the commencement of the experiments, composite surface soil samples were collected from each plot to characterize the initial soil conditions, and to guide fertilizer application rates. Each field was divided into 64 subunits, from which a composite soil sample (formed by mixing 20 2.5 cm diam. core samples) was collected from the top 15 cm of each subunit to characterize the initial soil conditions. Selected soil chemical characteristics of each site is presented in Table 1.

Table 1 Selected chemical characteristics of the soil at the two locations for the field study

Chemical characteristics	Location	
	Ames	Jackson
pH	6.50 ± 0.02^a	6.78 ± 0.02
Organic C (g kg^{-1})	12.6 ± 0.31	10.6 ± 0.26
Bray-1 P (mg kg^{-1})	23.9 ± 3.69	27.4 ± 4.22
NO$_3$–N (mg kg^{-1})	1.41 ± 0.13	2.05 ± 0.19
NH$_4$–N (mg kg^{-1})	2.44 ± 0.15	3.09 ± 0.20
SO$_4$–S (mg kg^{-1})	3.04 ± 0.58	3.85 ± 0.73
Exchangeable K (cmol kg^{-1})	81.3 ± 3.92	92.4 ± 4.46
Exchangeable Ca (cmol kg^{-1})	734 ± 41.5	693 ± 39.2
Exchangeable Mg (cmol kg^{-1})	65.8 ± 3.19	68.7 ± 3.33
Zn (mg kg^{-1})	0.60 ± 0.03	3.05 ± 0.17

[a] Numbers are mean values of 64 replicates $\pm$ SE

Field layout and treatment application

The field experiments were conducted in 2012 and 2013 at two sites: one at the West Tennessee Research and Education Center (WTREC) at Jackson, TN and the other at the Ames Plantation at Grand Junction, TN. The soil the Jackson is classified as Memphis silt loam soil (fine-silty, mixed, active, thermic Typic Hapludalfs), and the one at Ames Plantation is Lexington silt loam soil (fine-silty, mixed, active, thermic Ultic Hapludalfs) (Soil Service Staff 2009). The two sites had different land management practices. Whereas the land at the Jackson experimental site was under no till conservation system, the site at Ames was under the conventional plow system.

The study was a 3 × 4 factorial experiment (three N sources and four application rates) with an individual plot size of 9.1 × 6.1 m, in Jackson and 9.1 × 4.6 m in Ames. Each treatment was replicated four times in a randomized complete block design. Thus, 48 plots (12 plots/block and 4 blocks) were established in total. The treatments were arranged in a split-plot randomized complete block design with fertilizer types as main plots and N application rates as subplots. The N fertilizer types utilized for the experiments were: OENF (14.9% N, 4.3% P_2O_5, 18.1% S, 0.6% Fe, 3.3% OC), ammonium sulfate (21% N, 24% S), and urea (46% N).

In 2011, a preliminary study was conducted at the Jackson site to ascertain the fertilizer application rates for the various treatments. In that study, N rates used were: 0, 85, 170, and 255 kg N ha^{-1}. Results from that study showed no yield benefits resulting from the additional N supplied in the highest N application rate (Table 2), therefore the actual experiments were designed with modified N rates of 0, 85, 128, and 170 kg N ha^{-1}.

The entire OENF and ammonium sulfate were applied basally after corn planting, but before emergence of the seedlings. For the urea treatment, one third of each N rate was applied basally; the other two thirds were applied as two equal splits at the six leaf-collar growth stage (V6) and at tasseling (VT) to avoid excessive N losses. The basal application of ammonium sulfate and three split applications of urea mimicked the common N management practices used in many African countries. Overall, a systems approach was used to compare the three N sources in this study, where the actual treatment effects included the effects of not only N source, but also the S nutrient and N application timing. All three N fertilizer sources were surface applied. Phosphorus, K, and Zn were all applied at the following uniform rates across all treatments: 45 kg P ha^{-1}, 85 kg K ha^{-1}, and 5 kg Zn ha^{-1}. Phosphorus was applied as triple super phosphate (TSP, 0-45-0). The OENF contained P (4.3% P_2O_5) so at the 85, 128, and 170 kg N ha^{-1} rates, it supplied 23.8, 35.8, 47.6, and 71.4% of the uniform P rate, respectively. Therefore, only the additional TSP to meet the uniform P rate was applied in those treatments. Since the OENF and the ammonium sulfate fertilizer sources contained S (18 and 24% respectively), adequate quantities of S was applied to the urea treatments to eliminate the confounding effects of S on the fertilizer sources.

Planting of corn

Corn cv Dekalb 6483 (YieldGardVT Triple) hybrid was planted across all locations and years in this study. The experiment at Jackson was planted under no-tillage condition with eight rows per plot and the one at Ames was planted under plowed conditions with six rows per plot. The recommended row spacing followed at each location was 76.2 cm, resulting in a seeding rate of 79,000 plants ha^{-1}.

Plant measurements, harvesting, and analyses

Plant measurements included plant height at V6 and R1; above-ground plant dry weight at R1 and R6; grain yield; ear length and weight; ear and kernel count; ear grain weight; kernel weight; physiological defects, disease infestation, and pest attack and health ratings of corn ears.

Plant height was measured by randomly selecting and averaging the heights of 10 plants from the four central rows in each plot at the V6 and R1 growth stages. Plant height at V6 was determined from the highest fully extended leaf at the point on the leaf where it had leveled-off such that it was parallel to the ground, and at R1, it was determined from the base of the tassel. Plant biomass samples at R1 and R6 were collected by hand harvesting 12 corn plants randomly selected from the four center rows. The 12 plants were weighed using a Cardinal Detecto weighing scale model HSDC-40 (Webb City, MO) to obtain a fresh weight. From those 12 plants, a two-plant subsample

Table 2 Means of plant height, plant biomass, grain yield, and yield components of maize from fertilizer types and N rates for the preliminary study at Jackson in 2011

	V6 plant height (cm)	Anthesis plant height	R6 dry weight (Mg ha^{-1})	Grain yield	Ear count[a] Ear stalk^{-1}	Ear length (cm)	Ear weight (g)	Kernel mass	Kernel count[a] Kernel cob^{-1}	Grain weight (g ear^{-1})
Fertilizer										
Urea	47.80b	226.98a	17.87a	6.68b	0.99a	17.11a	152.88a	0.27a	453.06a	122.56a
Ammonium sulfate	48.10b	232.82a	18.03a	6.22ab	0.97a	16.92a	140.91a	0.26a	444.37a	118.13a
Organic enhanced	48.47b	233.57a	18.53a	6.09a	0.97a	16.89a	139.19a	0.26a	432.23a	116.19a
N rate (kg ha^{-1})										
0	42.88a	209.76a	13.59a	4.35a	0.96a	15.00a	106.93a	0.23a	362.48a	83.65a
85	47.01b	233.73b	19.14b	6.68b	0.99a	17.17b	151.45b	0.27b	459.27b	124.78b
170	48.01b	236.57b	20.16b	7.09b	0.96a	17.93c	165.58b	0.29b	478.76b	139.04c
255	48.05b	238.55b	20.04b	6.97b	0.98a	17.82bc	157.64b	0.28b	472.34b	132.06bc

Means joined by the same letter are not significantly different using Fisher's protected LSD at 0.05 level

[a] Analysis of counts was done modeling with a Poisson distribution and data transformed as y' = ln(y + 1). Means shown in original units

at R1 and a three-plant subsample at R6 were weighed and oven-dried at 65 °C (until the weights became stable), for the calculation of dry weights for the entire biomass harvest.

At physiological maturity, the four center rows of each plot were harvested using small plot combines with automatic weighing scales and moisture meters, for the determination of grain yield. All grain yields were adjusted to a moisture content of 15.5%. After taking three ears at harvest from each plot for moisture content determination, the remaining corn ears were utilized for corn ear analysis. Kernel counts were done using an International Marketing and Design Co. (San Antonio, TX) seed counter model 850-3. For the ear health ratings, three types of ear abnormalities were measured: physiological defects, disease infestation, and insect attack. A scale of four degrees was developed and used to describe the magnitude of each abnormality type qualitatively as: no damage (0), low damage (1), medium damage (2), and severe damage (3).

Statistical analyses

Analysis of variance (ANOVA) was conducted separately per location following a split plot randomized complete block design using a generalized linear mixed model (PROC GLIMMIX, SAS 9.4), (SAS Institute Inc. 2013) continuous variables such as grain yield, plant height, ear length, etc. were modeled with the normal distribution while the count related variables number of ears per stalk and number of kernels per cob were modeled with the Poisson distribution and a natural log transformation. Fertilizer type, N rate, and year were used as fixed effects in the model, while the blocks and block*fertilizer (year) were used as random effects.

The response variable in the ear health analysis was the number of ears damaged classified by four degrees of damage: none = 0, low = 1, medium = 2 and high = 3. Data was analyzed with an ANOVA model fitted to the Poisson distribution and a log transformation (Stokes et al. 2012).

Results and discussion

Weather conditions during the experimental period

Weather conditions throughout the duration of this study varied considerably. In general, 2013 was a cooler year compared to 2011 and 2012 particularly during the spring months of March, April, and May (Fig. 1). Temperatures in 2012 were as much as 5.6–8.3 °C warmer than average temperatures during

Fig. 1 Average monthly temperatures during the duration of this study
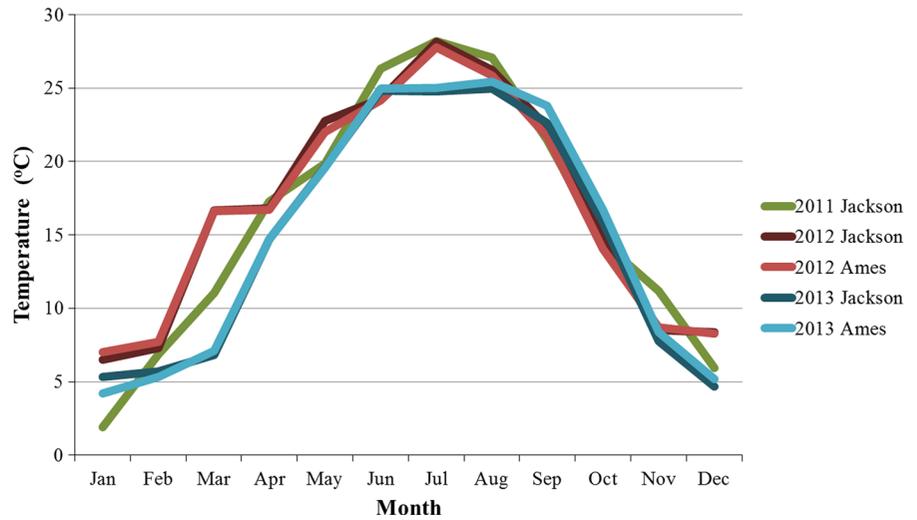
Fig. 2 Average monthly precipitation during the duration of this study
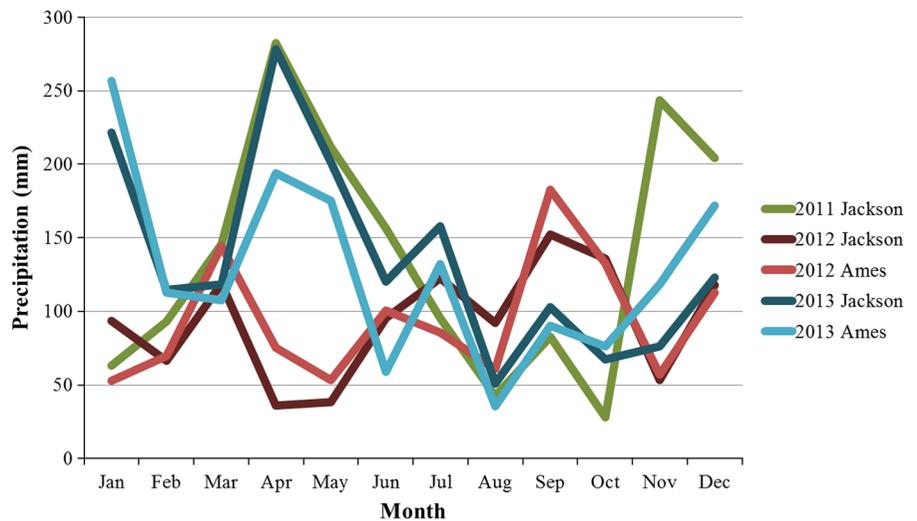
that same time period. On the other hand, 2011 and 2012 were both approximately 3.3 °C warmer than 2013 during the whole month of July. Temperatures from August to the end of the growing season, however, were relatively similar to each other across location-years. Monthly precipitation averages were even more variable (Fig. 2). Jackson had a particularly wet spring in 2011 and 2013 with approximately 494.3 and 479.5 mm of rainfall, respectively, between April and May. At Ames in 2013, the average monthly precipitation was moderate at 369.3 mm within the same time period. In sharp contrast, in 2012 both Jackson and Ames were much drier with only 74.2 and 128.5 mm of rainfall, respectively, between the spring months of April and May. Between June and August,

precipitation trends were fairly similar across location-years, but towards the end of the growing season the precipitation trends reversed from what they had been during the spring: Jackson and Ames in 2012 had considerably more precipitation (288.0 and 315.2 mm, respectively) between the months of September and October, whereas Jackson in 2011 and 2013 and Ames in 2013 were much drier (111.0, 170.2, and 166.4 mm, respectively) during the same time period.

Effects of OENF on plant height and dry matter yield at anthesis

The plant height at V6 stage was significantly higher with the application OENF than urea because OENF

plants had received all their N fertilizers while only a third of urea was applied up to V6 stage (data not shown). During the 2012 growing season, due to the unfavorable weather conditions, there was no effect of the fertilizer types and N rates on plant height at anthesis. However, during the 2013 growing season in Jackson, the OENF and the ammonium sulfate treatments produced significantly taller plant at anthesis than urea when N rates $\geq$85 kg ha^{-1} (Fig. 3). The plant height at anthesis for the urea treatment reached a peak at N application rate of 128 kg N ha^{-1} and declined at the higher N rate. The plant height at anthesis for the OENF and ammonium sulfate treatments, on the other hand, reached a maximum plant height of ~220 cm at N application rate of 170 kg N ha^{-1} (Fig. 3). Contrary to the observation at Jackson, the plant height at anthesis at the Ames location did not show any significant effects of fertilizer type and N application rate (Fig. 3).

In Ames, there was a significant fertilizer type*N rate*Year interaction ($p < 0.05$) on plant biomass at anthesis. During the 2012 growing season, fertilizer types did not show significant effects on plant biomass at anthesis at any of the N rates tested in the range 0–170 kg ha^{-1}. Conversely in the 2013 growing season, the OENF and ammonium sulfate treatments produced significantly greater plant biomass at anthesis than the urea treatment at N rates $\geq$85 kg ha^{-1} (Fig. 4). Irrespective of the fertilizer type, plant

biomass increased with increasing N rate, achieving the greatest values at 170 kg N ha^{-1} (Fig. 4). Similarly to the results obtained in Ames, there were fertilizer type*N rate*Year interactions in the results obtained from Jackson. In 2012, the treatments with OENF and ammonium sulfate produced greater plant biomass than those of the treatment with urea at N rates of 85 and 128 kg N ha^{-1}(Fig. 5) At 170 kg N ha^{-1}, however, there was no difference in plant biomass among the fertilizer types. This is because, whereas the plant biomass of the OENF and ammonium sulfate treatments peaked at N rate of 128 kg ha^{-1}, that of urea treatment increased with increasing N rate, reaching a maximum weight at N rate of 170 kg ha^{-1}. In 2013, similar trends were observed, with the OENF and ammonium sulfate fertilizer treatments producing significantly larger plants than that of the urea treatment. Unlike the observation in 2012, plant biomass of the urea treatment peaked at N rate of 128 kg ha^{-1}, whereas that of the ammonium sulfate treatment continued to increase with increasing N application rate (Fig. 5).

The marked differences in plant biomass observed between the two locations are likely due to differences in land management between the two locations. Whereas the Jackson experiment was conducted on a no-till land, the Ames experiment was conducted on a plowed land. Studies have shown that no till practices minimize soil disturbance and increase soil residue


Fig. 3 Effects of fertilizer types and rate of application on corn plant height at anthesis during the 2013 growing season at Ames and Jackson, TN
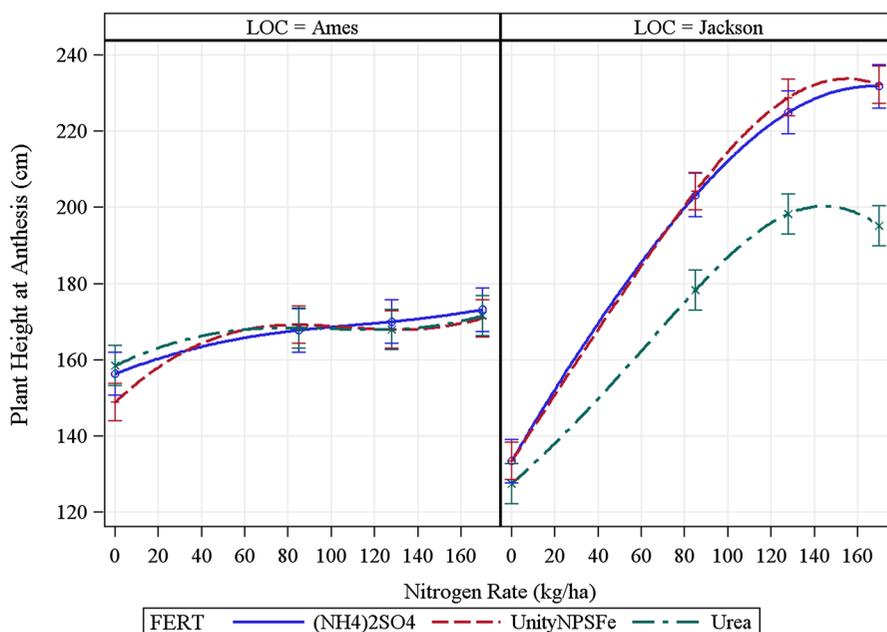
Fig. 4 Effects of fertilizer types and rate of application on corn biomass weight at anthesis during the 2012 and 2013 growing seasons at Ames, TN
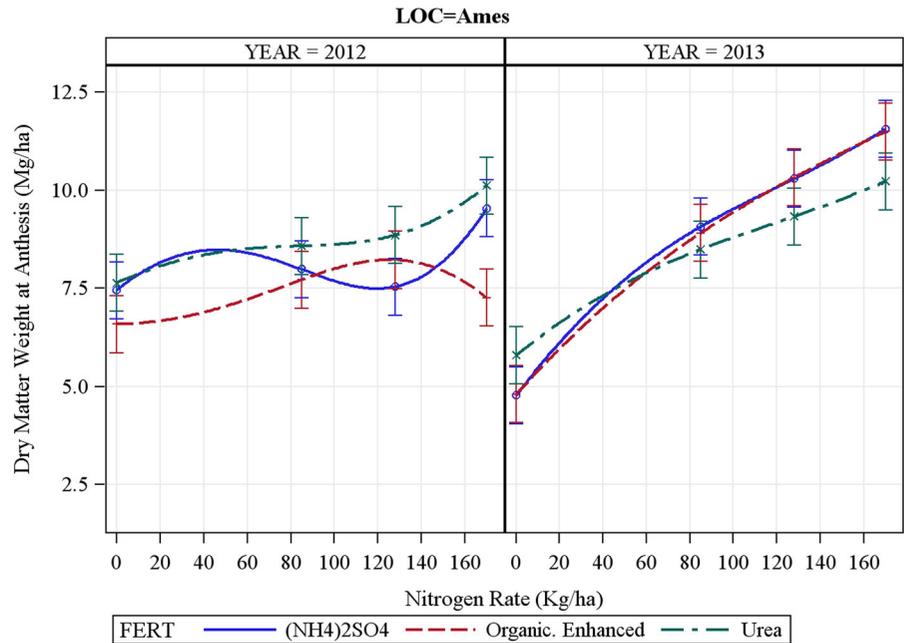
Fig. 5 Effects of fertilizer types and rate of application on corn biomass weight at anthesis during the 2012 and 2013 growing seasons at Jackson, TN
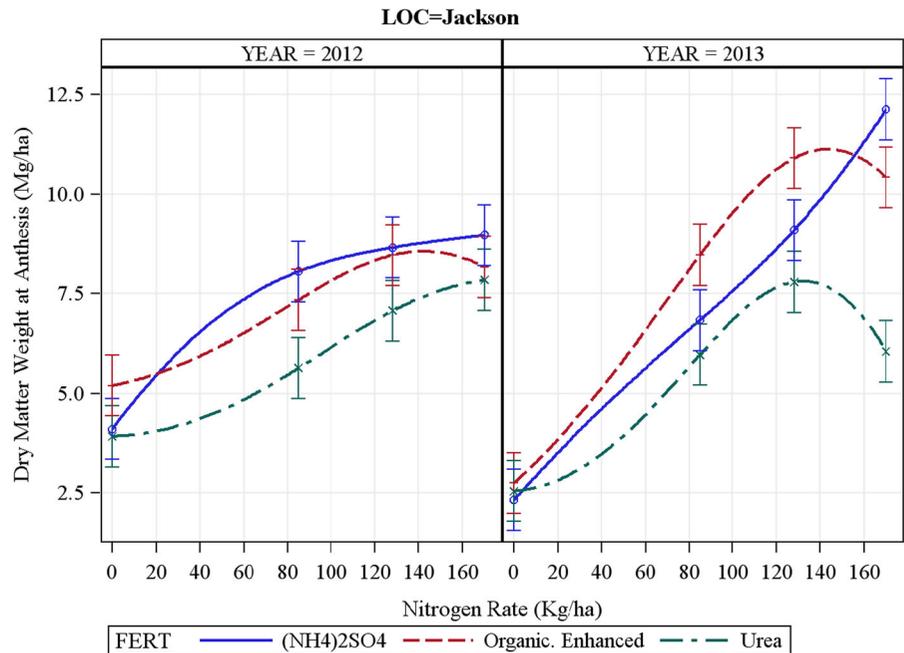
cover (Hobbs et al. 2008). These practices tend to help mitigate the environmental impact of corn production by reducing soil loss and nutrient runoff (Angle et al. 1984; Wendt and Burwell 1985; Shipitalo et al. 2013). No till improves soil physical properties such as infiltration, bulk density, water retention, structure, and water-stable aggregates (Karlen et al. 1994; Cassel

et al. 1995; Kumar et al. 2012a, b). Conversely, Pierce et al. (1994) reported that intensive cropping systems based on mechanical soil movement induced fertility loss along with the reduction of soil water holding capacity in most agricultural areas of the world. Also, the marked differences in plant biomass between years could be attributed the differences in rainfall amounts

and distribution. The 2012 growing season was generally drier, compared to 2013 growing season (Figs. 1, 2). The effect of lower rainfall on biomass production was more evident at Ames under conventional tillage.

The fact that the OENF did not out-yield ammonium sulfate in our study is in contrast to the finding of Magdoff and Amadon (1980) who observed that silage yields from biosolids amended fields were greater than mineral N-fertilization alone. However, in this study additional P was added to ammonium sulfate and urea treatments to compensate for P supplied by OENF. The data from this study demonstrates that the N-rate related variability is higher than the fertilizer type related variability (Figs. 4, 5).

Effects of OENF on grain yield and yield components

There were significant Year*Fertilizer type*N rate interactions ($p < 0.05$) on grain yield (Figs. 6, 7). Consistent with the plant biomass at anthesis, in both locations, grain yields were lower during the 2012 growing season than the 2013 growing season, due to the drier conditions during the 2012 growing season (Figs. 1, 2). Using the grain and biomass yields, harvest index (HI) was calculated as ratio of grain

yield to total biomass yield (Pagani et al. 2012). Consistent with the observation from other studies (Moser et al. 2006; Azizi and Soleymani 2012), the weather conditions had a significant effect on the HI. During the drier weather (2012 growing season), HI across all three N sources were generally low with highest values ranging between 0.3 and 0.4, not significantly impacted at N application rated >85 kg N ha^{-1}, and for both the Ames field (Fig. 8) and Jackson Field (data not presented). However during the 2013 growing season, HI increased with increasing rate of N application across all N sources, reaching a maximum value of 0.65 for the OENF and urea treatments and 0.6 for the ammonium sulfate treatment in the Ames field (Fig. 8). Similar trends were observed for the Jackson field (data not presented). Several studies have shown that, among other factors, drought and soil moisture conditions significantly affect HI of most crops (Moser et al. 2006; Azizi and Soleymani 2012; Pagani et al. 2012).

The effect of the weather conditions was reflected in the measured yield components of ear length, ear count, ear weight, and grain weight. Whereas in 2012 in Jackson, a maximum ear length was 14 cm, and average grain weight per ear was 90 g, in 2013, the maximum ear length was 18 cm, and average grain weight per ear was 130 g (data not presented). In 2012,


Fig. 6 Effects of fertilizer types and rate of application on corn grain yield during the 2012 and 2013 growing seasons at Ames, TN
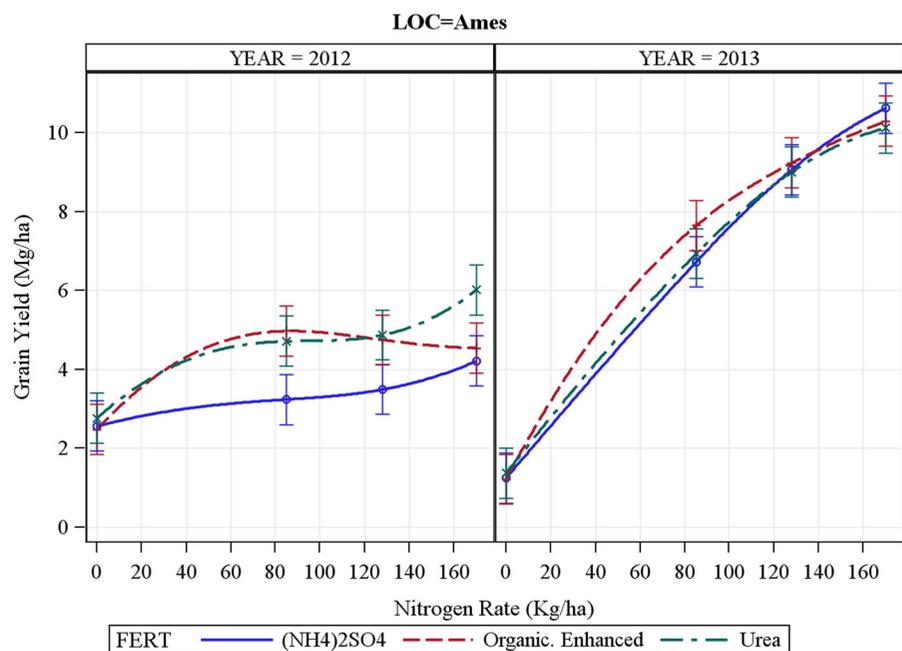
Fig. 7 Effects of fertilizer types and rate of application on corn grain yield during the 2012 and 2013 growing seasons at Ames, TN
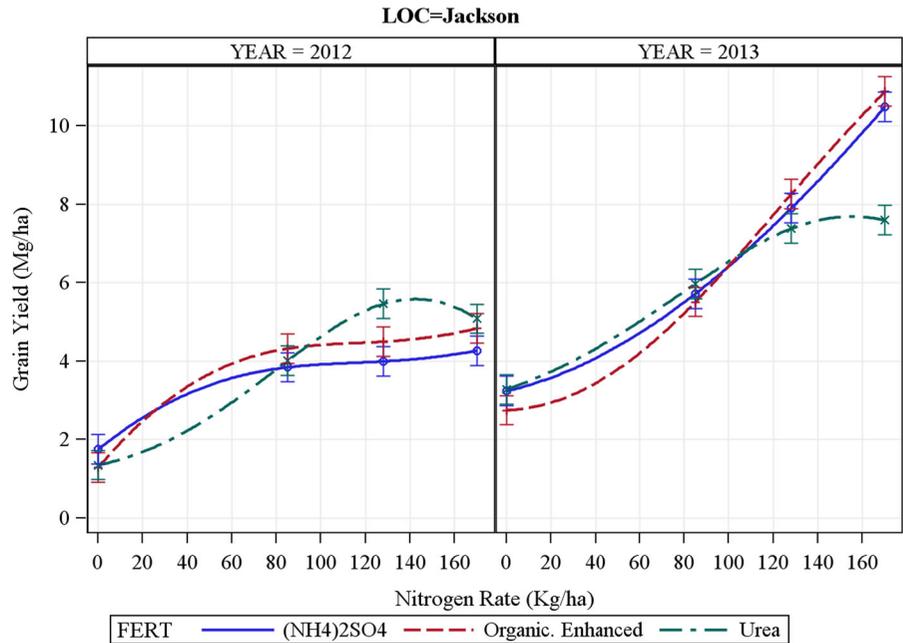

Fig. 8 Effects of fertilizer types and rate of application on corn harvest index during the 2012 and 2013 growing seasons at Ames, TN
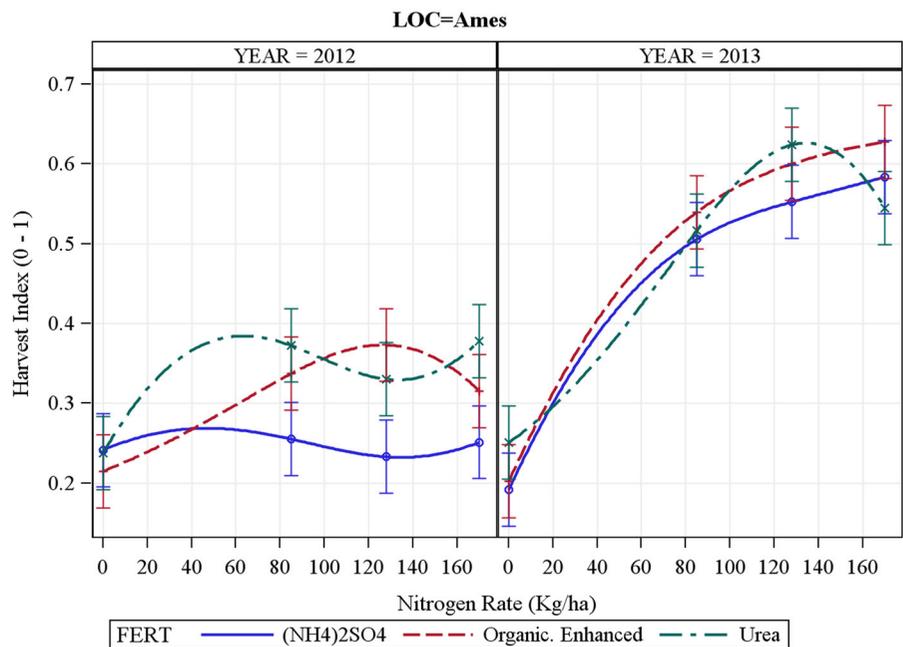
at both locations, grain yields showed greater variability with significantly lower yields occurring in the ammonium sulfate treatment in Ames (Fig. 6). In Jackson, there was no significant difference in grain yield among the fertilizer types at N rates of 85 and 170 kg ha^{-1}. However, at 128 kg N ha^{-1}, grain yield from the OENF treatment was significantly greater than those of the urea and ammonium sulfate treatments. The OENF contained 4.3% P_2O_5, therefore applying that fertilizer required 24–48% less P, than that was applied to the urea and ammonium sulfate treatments. Thus, supplying less P and yet not having any reduction in grain yield could be a savings to the farmer. The variability in grain yield during the 2012 growing season could be attributed to a short rainfall that occurred during the grain filling stage. Thus, the

Fig. 9 Effects of rate of N application and year on physical damage during the 2012 and 2013 growing seasons at **a** Ames and **b** Jackson, TN
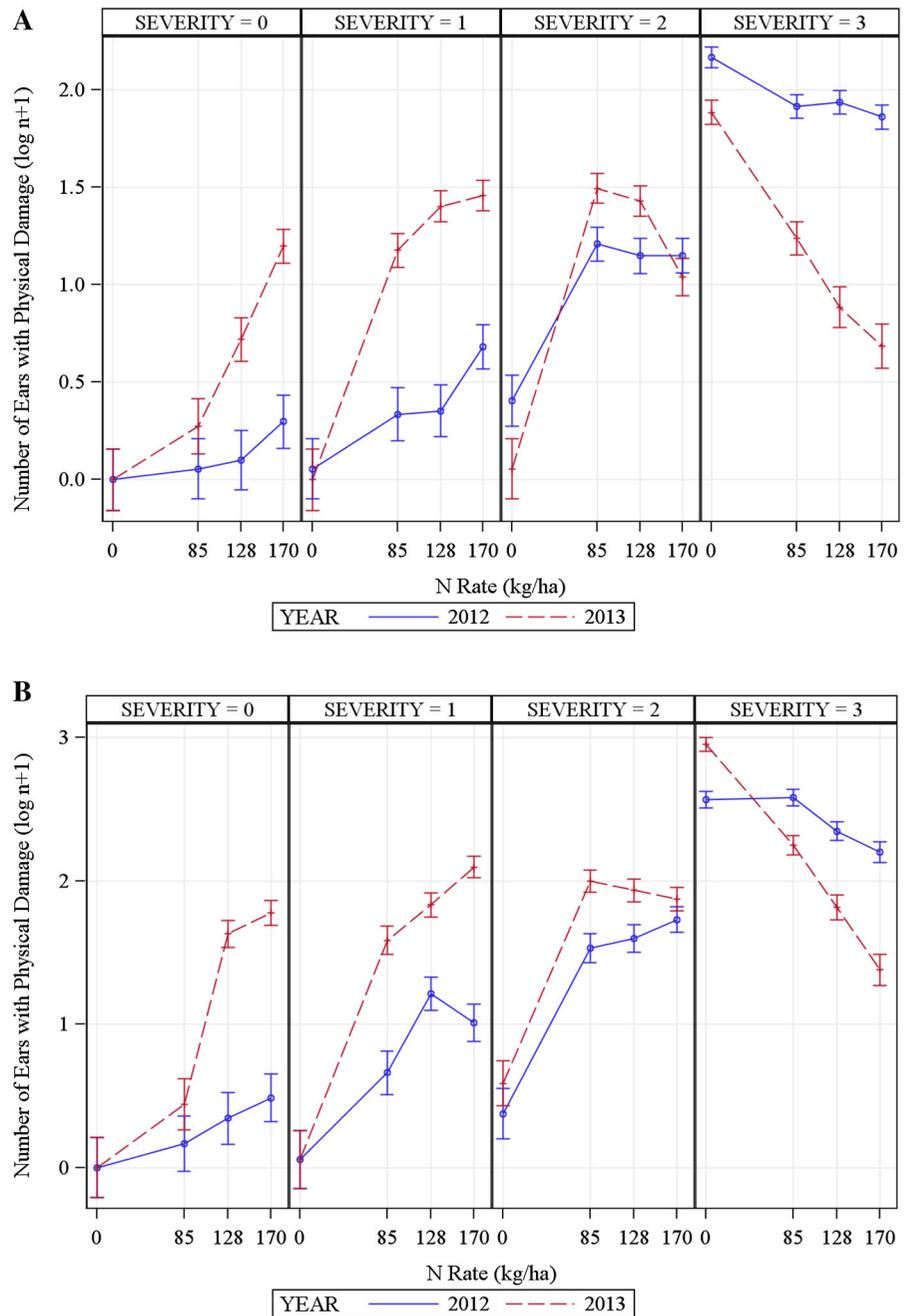
grain yields obtained were greatly confounded by soil moisture conditions. During the 2013 growing season, grain yield from the Ames location increased with N rate, irrespective of the fertilizer type, with no significant differences among the fertilizer types (Fig. 6). At the Jackson location, similar trends were obtained at N rates ≤ 128 kg N ha^{-1}. However, similarly to the biomass yields, grain yields of the urea treatment peaked and did not increase when N rate was increased to 170 kg N ha^{-1} (Fig. 7). Several studies have shown yield plateaus occurring in corn at N rates between 85 and 128 kg N ha^{-1} (Ayoola and Makinde [2009](); Crozier et al. [2014](); Sindelar et al. [2012](); Halvorson and Reule [2007](); Miao et al. [2006]();

Fig. 10 Effects of fertilizer types and rate of application on (**a**) physical damage during the 2012 growing season at Jackson, TN, (**b**) disease damage during the 2012 growing season at Jackson, TN, and (**c**) disease damage during the 2013 growing season at Jackson, TN
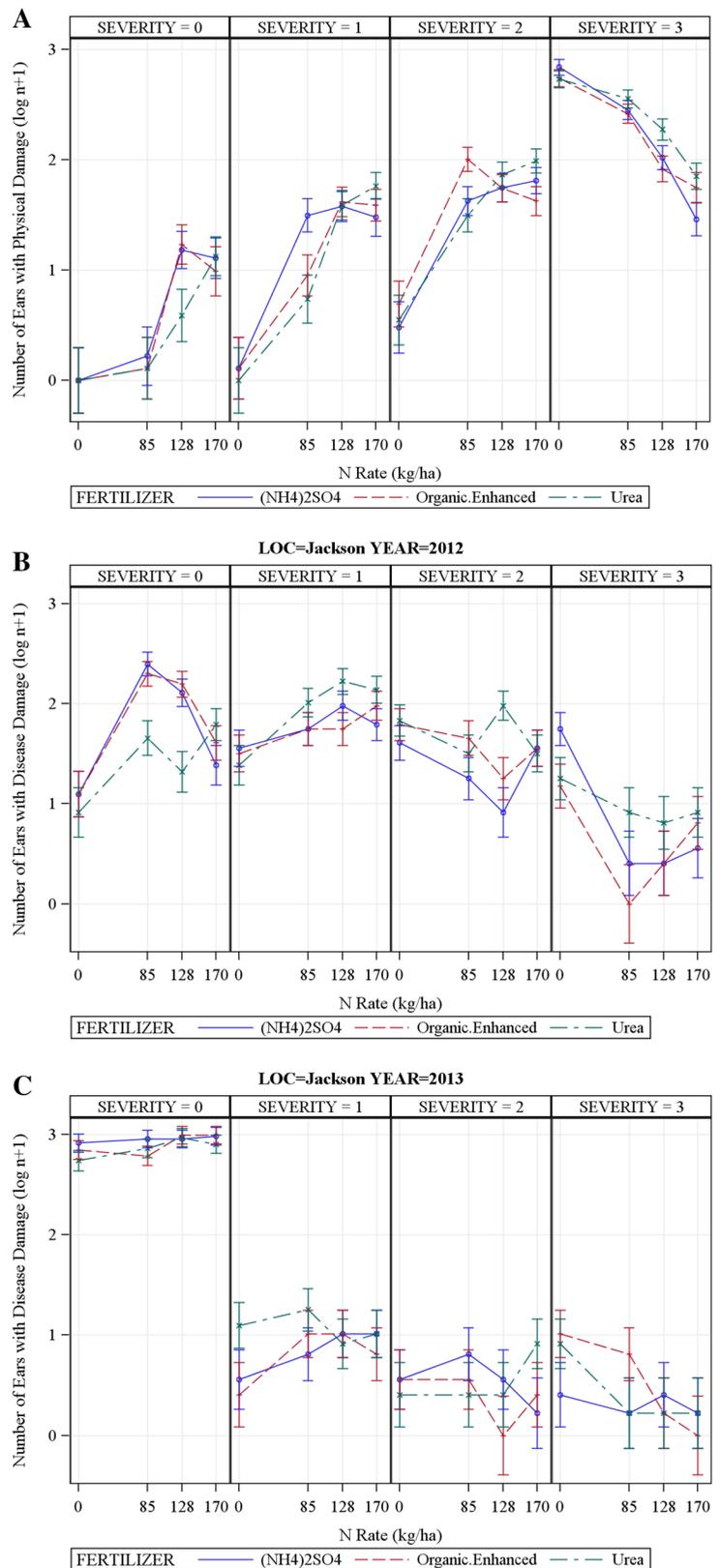
Shapiro and Wortmann 2006; Durieux et al. 1995) similar to the ones shown by the urea treatment in Jackson.

Effects of OENF on ear health

For a fertilizer type or group of fertilizers to be associated with a particular type of ear health condition, the number of ears associated with that fertilizer or group of fertilizers must be significantly higher than the other fertilizers in categories 2 and 3 severity level. In Ames, none of the effects in the analysis of variance was significant to suggest relationships between disease- and physical-damaged ears and fertilizer types. However, the effect of Years × N rate × Severity was significant at both Ames and Jackson (Fig. 9). Although 2012 was a drier year, the rainfall distribution was greater during grain-filling period (Fig. 2) leading to greater disease and physical damage of the highest severity level (Fig. 9). At Jackson, at the highest severity, urea application resulted in greater physical damage than OENF and ammonium sulfate (Fig. 10). Similar trend was also observed with disease damage in 2012 (Fig. 10). In the more favorable year (2013), fertilizer type had no significant impact on disease damage at either location.

At the highest severity level, both physical- and disease-damage declined with increasing rate of N application (Figs. 9, 10). Possibly, the fertilizer application, which produced robust corn stalks, enabled the plants to resist disease incidence much better. Although several studies have shown that over application of N fertilizer increases the incidence of corn smut disease (Aydogdu and Boyraz 2011; Kostandi and Soliman 1997), other studies have also shown that adequate nutrient supply enable plant to withstand numerous plant disease damage (Ghorbani et al. 2009; Johnston 2000). Thus, based on the above results, the occurrence and severity of disease and physical damage of corn will not increase on application of OENF.

Summary and conclusions

Dry conditions during critical stages of the corn crop in 2012 did not allow the expression of fertilizer characteristics either in crop growth or grain yield,

dominance of random variability over the expected variability due to the fertilizers did not permit the performance comparison of the OENF with the other two conventional fertilizers. Environmental conditions conducive for corn production in 2013, however, allowed to express the effects of the fertilizers on crop growth and grain yield. The combined results from the two locations with contrasting soil management strategies show that the OENF and ammonium sulfate produced plant biomass significantly greater than that of urea at N rates of ≥ 85 kg ha^{-1}. Although less P was applied to the OENF treatments, grain yields from the OENF were similar to those from both ammonium sulfate and urea at N rate of ≤ 128 kg N ha^{-1}, but significantly greater than those from urea at 170 kg N ha^{-1}. The fertilizer types used did not have any significant effects on disease and physical damage to the corn ears. The combined data suggest that that the OENF could be an alternative N source for crop production. It also provides S, Fe, and some or all of P requirements for crop production. Therefore, with additional environment benefits of encouraging recycling of municipal and domestic waste, we conclude that the use of OENF should be incorporated in various corn production systems.

References

Angle JS, McClung G, McIntosh MS, Thomas PM, Wolf DC (1984) Nutrient losses in runoff from conventional and no-till corn watersheds. J Environ Qual 13:431–435

Aydogdu M, Boyraz N (2011) Effects of nitrogen and organic fertilization on corn smut (Ustilago maydis (DC) Corda.). Afr J Agric Res 6:4539–4543

Ayoola OT, Makinde EA (2009) Maize growth, yield and soil nutrient changes with N-enriched organic fertilizers. Afr J Food Agric Nutr Dev 9:580–592

Azizi S, Soleymani A (2012) Effect of removal of top leaves before and after anthesis on seed yield and harvest index of corn (KSC 540). Res Crops 13:852–856

Binder DL, Sander DH, Walters DT (2002) Maize response to time of nitrogen application as affected by level of nitrogen deficiency. Agron J 92:1228–1236

Cassel D, Raczkowski C, Denton H (1995) Tillage effects on corn production and soil physical conditions. Soil Sci Soc Am J 59:1436–1443

Crozier CR, Gehl RJ, Hardy DH, Heiniger RW (2014) Nitrogen management for high population corn production in wide and narrow rows. Agron J 106:66–72

Durieux RP, Brown HJ, Stewart EJ, Zhao JQ, Jokela WE, Magdoff FR (1995) Implications of nitrogen management

strategies for nitrate leaching potential: roles of nitrogen source and fertilizer recommendation system. Agron J 87:884–887

Economic Research Service (2013) Cost production forecasts. The United States, Department of Agriculture, Washington. www.ers.usda.gov/Data/CostsAndReturns/testpick. htm#historic2. Accessed Nov 2013

Ghorbani R, Wilcockson S, Koocheki A, Leifert C (2009) Soil management for sustainable crop disease control: a review. Environ Chem Lett 6:149–162

Halvorson AD, Reule CA (2007) Irrigated, no-till corn and barley response to nitrogen in northern Colorado. Agron J 99:1521–1529

Hobbs PR, Sayre K, Gupta R (2008) The role of conservation agriculture in sustainable agriculture. Philos Trans R Soc Lond B Biol Sci 363:543–555

Jenkinson DS (2001) The impacts of humans on the nitrogen cycle, with focus on temperate arable agriculture. Plant Soil 228:3–5

Johnston AE (2000) Efficient use of nutrients in agricultural production systems. Commun Soil Sci Plant Anal 31:1599–1620

Karlen D, Wollenhaupt N, Erbach D, Berry E, Swan J, Eash N, Jordahl J (1994) Long-term tillage effects on soil quality. Soil Tillage Res 32:313–327

Kostandi SF, Soliman MF (1997) Smut disease incidence and mineral composition of corn as affected by N fertilizer sources and K application rates. J Agron Crop Sci 178:197–204

Kumar S, Kadono A, Lal R, Dick W (2012a) Long-term tillage and crop rotations for 47–49 years influences hydrological properties of two soils in Ohio. Soil Sci Soc Am J 76:2195–2207

Kumar S, Kadono A, Lal R, Dick W (2012b) Long-term no-till impacts on organic carbon and properties of two contrasting soils and corn yields in Ohio. Soil Sci Soc Am J 76:1798–1809

Magdoff FR, Amadon JF (1980) Nitrogen availability from sewage sludge. J Environ Qual 9:451–455

Miao Y, Mulla DJ, Robert PC, Hernandez JA (2006) Within-field variation in corn yield and grain quality responses to nitrogen fertilization and hybrid selection. Agron J 98:129–140

Moser SB, Feil B, Jampatong S, Stamp P (2006) Effects of pre-anthesis drought, nitrogen fertilizer rate, and variety on grain yield, yield components, and harvest index of tropical maize. Agric Water Manag 81:41–58

NSF International (2010) NSF Protocol P353. Sewage sludge sterilization in organically enhanced granular fertilizer production. NSF Int., Ann Arbor. www.nsf.org/business/engineering_and_research/protocols.asp?program=EngineeringSer. Accessed 2 Mar 2016

Pagani A, Echeverria HE, Andrade FH, Sainz Rozas HR (2012) Effects of nitrogen and sulfur application on grain yield, nutrient accumulation, and harvest indexes in maize. J Plant Nutr 35:1080–1097

Pierce F, Fortin M, Staton M (1994) Periodic plowing effects on soil properties in a no-till farming system. Soil Sci Soc Am J 58:1782–1787

Robertson GP, Vitosek PM (2009) Nitrogen in agriculture: balancing the cost of an essential resource. Annu Rev Environ Resour 34:97–105

SAS Institute Inc (2013) Base SAS® 9.4 utilities: reference. SAS Institute Inc, Cary

Shapiro CA, Wortmann CS (2006) Corn response to nitrogen rate, row spacing, and plant density in eastern Nebraska. Agron J 98:529–535

Shipitalo MJ, Owens LB, Bonta JV, Edwards WM (2013) Effect of no-till and extended rotation on nutrient losses in surface runoff. Soil Sci Soc Am J 77:1329–1337

Sindelar AJ, Lamb JA, Sheaffer CC, Jung HG, Rosen CJ (2012) Response of corn grain, cellulosic biomass, and ethanol yields to nitrogen fertilization. Agron J 104:363–370

Singh U, Austin ER, Sanabria J, Agyn-Birikorang S (2012) Nitrogen transformation, ammonia volatilization loss, and nitrate leaching in organically-enhanced nitrogen fertilizers relative to urea. Soil Sci Soc Am J 76:1842–1854

Soil Survey Staff (2009) Soil survey field and laboratory methods manual. In: Burt R (ed) Soil survey investigations report no. 51, version 1.0. U.S. Department of Agriculture, Natural Resources Conservation Service, Washington

Stokes ME, Davis CS, Koch GG (2012) Categorical data analysis using SAS, 3rd edn. SAS Institute, Cary

Wendt R, Burwell R (1985) Runoff and soil losses for conventional, reduced, and no-till corn. J Soil Water Conserv 40:450–454