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Soil Nutrient Levels after Corn Harvest under NPSFe Biofertilizer and NPKZn Briquettes

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ABSTRACT

Interest in the use of alternate fertilizers has increased in recent years for improving crop nutrition and soil health. The efficacy of these fertilizers on corn (Zea mays L.) production has not been well documented. Alternate fertilizers organically enhanced NPSFe biofertilizer (NPSFe) manufactured from sterilized organ-ic additives extracted from municipal wastewater biosolids and NPKZn briquettes (briquettes) produced by compacting commer-cially available solid fertilizers into a super-granule between 1-3 grams were evaluated for nutrient concentrations in the soil rel-ative to common fertilizers ammonium sulfate (+P+K) and urea (+P+K) at Jackson and Grand Junction, TN from 2011 to 2013. NPSFe, the briquettes, ammonium sulfate, and urea and four N application rates of 0, 85, 128/170, and 170/255 kg ha^{-1} were as-signed to the main and sub plots, respectively, in a split plot ran-domized complete block design with four replicates. Soil at a 0-15 cm depth was analyzed for Bray P, NO_3^--N, NH_4^+-N, SO_4^{2-}-S, and organic C concentrations after corn harvest. The briquettes produced lower soil NO_3^--N concentrations than the other fertil-izers particularly under wet soil conditions. NPSFe sometimes had higher post-harvest soil NH_4^+-N than the briquettes and am-monium sulfate. NPSFe sometimes tended to be higher than the other fertilizers in post-harvest soil P concentrations after corn harvest, thus the P provided by NPSFe may be less avail-able than TSP. NPSFe and ammonium sulfate both increased post-harvest soil SO_4^{2-}-S levels compared to the briquettes and urea, particularly at higher application rates. NPSFe had greater soil organic C level than the other fertilizers. In conclusion, NPS-Fe consistently increases soil organic C level, particularly at the higher N rates, within three years of experimentation, which may promote microbial activities and health of the soil.

Keywords: Biofertilizer, Briquettes, Corn, Nitrogen, Phosphorus, Sulfur, Carbon

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List of Abbreviations
NPSFe biofertilizer, NPSFe
NPKZn briquettes, briquettes

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INTRODUCTION

Urea and ammonium sulfate are among the most common N fertilizers used by farmers to improve soil fertility and thus increase crop productivity, particularly in developing countries at present. More than five billion kilograms of urea and just under two billion kilograms of ammonium sulfate, were manufactured in the United States in 1997 (Pellegrino, 2000). Urea, as an N fertilizer, supplies no secondary or micronutrients to crops, and ammonium sulfate supplies only S in addition to N. As such, these fertilizers are unlikely to enhance crop mineral quality without the addition of other nutrients.

Two new alternate fertilizers, organically-enhanced NPSFe and NPKZn briquettes, are under development for improving plant mineral nutrition and nutrient concentration in crop grain. The organically-enhanced NPSFe fertilizer contains N (14.9%), P (4.3%), S (18.1%), and Fe (0.6%), and approximately 8% organic C that is made from sterilized organic additives extracted from municipal wastewater biosolids. Most of the N and all of the P, S, and Fe are contained in the municipal biosolid. Only N is supplemented with additional N mineral fertilizer to increase the N concentration of NPSFe during the manufacturing process.

The briquette fertilizer is mineral in form and supplies Zn in addition to NPK. The briquettes are made by a briquetter machine that simply compresses commercially available prilled fertilizers into a briquette approximately 2.43 grams in weight without any additional binder material. Thus the guaranteed analysis of the briquettes is variable depending on the proportions of different fertilizers used to form the briquette. A briquette with a smaller surface area to volume ratio will dissolve more slowly and thus release its nutrients in a more controlled manner over time reducing soil nutrient losses, particularly N. The application of the briquettes is by banding a couple of centimeters below the soil surface in between planted rows. A subsoil land application itself will also help to reduce ammonia volatilization (Mengel et al., 1982). In developing countries this may be a practical method of fertilizer application where lesser acreages are farmed by one producer and his/her family.

Previous studies conducted on soil nutrient concentrations under organic enhanced N fertilizer and briquette fertilization were limited. Singh et al. (2012) reported via incubation studies that both NH_3-N volatilization and NO_3^--N leaching losses were significantly lower with organic enhanced N fertilizer. These attributes of organic enhanced N fertilizer could potentially lead to reduced N application and less adverse environmental pollution. However, no field trial has been carried out to validate the conclusions from Singh et al. (2012). Khalil et al. (2011) found soil N to be much lower under urea super granules compared to surface applied prilled urea. Savant and Stangel (1990 and 1998) and Wetselaar (1985) confirmed that N and P concentrations in the flood water of flood irrigated rice to be much lower under briquette fertilization compared to conventionally prilled fertilizer.

These alternate fertilizers, NPSFe and the briquettes, are likely to have impacts on crop production and post-harvest soil fertility compared to the conventional fertilizers because of their different nutrient release patterns. The overall objective of this study was to compare alternate fertilizers, NPSFe and banded briquettes, relative to conventional fertilizers, ammonium sulfate (+ P, K, and Zn supplied separately) and urea (+ P, K, Zn and S supplied separately), in terms of mineral nutrition in plant biomass and grain, grain yield and quality, and post-harvest soil fertility under upland non-irrigated corn production. This article only presents the effects of NPSFe biofertilizer and NPKZn briquettes on post-harvest soil nutrient levels compared with ammonium sulfate and urea.

MATERIALS AND METHODS

Site Description

The field trial was conducted at the University of Tennessee's West Tennessee Research and

Education Center (WTREC) located in Jackson, Tennessee from 2011 to 2013 and at the Ames Plantation in Grand Junction, Tennessee from 2012 to 2013. The field trial was conducted on a Memphis silt loam soil (fine-silty, mixed, active, thermic Typic Hapludalfs) at Jackson and on a Lexington silt loam soil (fine-silty, mixed, active, thermic Ultic Hapludalfs) at Grand Junction. At both locations the fields used for this study prior to the experiment were in soybean production followed by a winter fallow.

Corn Planting

Corn cultivar, Dekalb 6483 (YieldGardVT Triple), was used across all locations and years in this study. The Jackson trial was planted under no-tillage as eight row plots with 76.2 cm (30 inch) row spacing at a seeding rate of 79,000 plants ha^{-1}; overall plot dimensions were 9.1 m by 6.1 m (30 feet by 20 feet). The Grand Junction trial was planted as tilled six row plots also with 76.2 cm row spacing at a seeding rate of 79,000 plants ha^{-1}; overall plot dimensions were 9.1 m by 4.6 m (30 feet by 15 feet). In 2011 corn was planted on 9 May at Jackson; in 2012 corn was planted on 18 April at Jackson and on 19 April at Grand Junction; in 2013 corn was planted on 17 April at Jackson and on 29 May at Grand Junction.

Treatments

Sixteen treatments with four blocks (64 plots in total per location) were laid out in a split plot randomized complete block design with fertilizer types as main plots and N application rates as subplots. The four fertilizer types were NPSFe, the briquettes, ammonium sulfate (21% N, 24% S), and urea (46% N).

In 2011 at Jackson the N rates used were 0, 85, 170, and 255 kg N ha^{-1}. From 2012 to 2013 at both locations the N rates used were 0, 85, 128, and 170 kg N ha^{-1} (Table 1). Since 2011 results showed no additional growth or yield benefits resulting from the highest N application rate, the two higher N rates after 2011 were adjusted to lower in order to better reflect a more economical fertilizing regime common to third world farming practices. As a result, the 2011 data (Jackson only) were analyzed independently from the other datasets while the data from 2012 and 2013 from Jackson and Grand Junction were analyzed collectively as a pool. For reporting purposes hereafter the data from Jackson 2011 will simply be referred to as “J11” and the pooled data from the location-years Jackson and Grand Junction in 2012 and 2013 will be collectively referred to as “JA1213”.

All the N fertilizer treatments except urea were applied basally after corn planting. In 2011 at Jackson fertilizers were applied the day after planting, in 2012 fertilizers were applied five days and 21 days after planting at Jackson and Grand Junction, respectively, and in 2013 fertilizers were applied five days and eight days after planting at Jackson and Grand Junction, respectively.

In all locations and years, only one third of the N in the urea fertilizer treatment was applied basally; the other two thirds of N in that treatment were applied as two equal splits later in the season at the six leaf growth stage (V6) and at tasseling. This was done, as farmers in developing nations typically do, to reduce N volatilization losses. NPSFe, ammonium sulfate, and urea were all applied as a uniform surface broadcast across the entire plot. The briquettes were banded using a small hand-driven plow approximately 2.54 cm below the soil surface between rows one and two, three and four, five and six, and seven and eight at Jackson. At Grand Junction the briquettes were banded at the same depth but in three bands between rows one and two, three and four, and five and six.

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} (Table 1). The S rate was variable for the NPSFe and ammonium sulfate fertilizer treatments because both of these fertilizers contained S as part of their guaranteed analysis, thus with increasing

N rates, NPSFe and ammonium sulfate supplied increasing amounts of S (Table 1). At the 85 kg N ha^{-1} rate, NPSFe and ammonium sulfate supplied 104 and 98 kg S ha^{-1}, respectively; at the 128 kg N ha^{-1} rate, NPSFe and ammonium sulfate supplied 156 and 147 kg S ha^{-1}, respectively; at the 170 kg N ha^{-1} rate, NPSFe and ammonium sulfate supplied 207 and 195 kg S ha^{-1}, respectively; and at the 255 kg N ha^{-1} rate, NPSFe and ammonium sulfate supplied 311 and 292 kg S ha^{-1}, respectively. For the control (0 kg N ha^{-1}), all the fertilizer treatment plots had an S rate of 1.25 kg S ha^{-1} from the sulfate in the $ZnO/ZnSO_4$ fertilizer.

Table 1. Treatment descriptions at Jackson and Grand Junction during 2011 to 2013.

Treatment Number	Fertilizer Type	N Rate	P Rate	K Rate	S Rate	Zn Rate
		kg ha^{-1}				
1	Ammonium sulfate	0	45	85	1.25	5
2	Ammonium sulfate	85	45	85	98†	5
3	Ammonium sulfate	128/170*	45	85	147/195	5
4	Ammonium sulfate	170/255**	45	85	195/292	5
5	NPSFe	0	45	85	1.25	5
6	NPSFe	85	45	85	104†	5
7	NPSFe	128/170	45	85	156/207	5
8	NPSFe	170/255	45	85	207/311	5
9	NPKZn briquettes	0	45	85	1.25	5
10	NPKZn briquettes	85	45	85	2.46††	5
11	NPKZn briquettes	128/170	45	85	2.46	5
12	NPKZn briquettes	170/255	45	85	2.46	5
13	Urea	0	45	85	1.25	5
14	Urea§	85	45	85	1.25	5
15	Urea	128/170	45	85	1.25	5
16	Urea	170/255	45	85	1.25	5

*, 2011 rate was 170 kg N ha^{-1}, 2012-13 rate was 128 kg N ha^{-1}.

**, 2011 rate was 255 kg N ha^{-1}, 2012-13 rate was 170 kg N ha^{-1}.

†, S rates were higher under ammonium sulfate and NPSFe and increased with increasing N rate because they contained 24.0% and 18.1% S, respectively.

††, S rates were slightly higher under applied briquette treatments than urea because Zn was supplied as ZnSO4 in the briquettes; in the other Zn applications $ZnO/ZnSO_4$ was used which has less overall SO_4.

§, urea was applied in three equal split applications: basally, V6 and VT growth stages.

Phosphorus was applied as triple super phosphate (TSP, 0-45-0) for the ammonium sulfate, urea, and NPSFe treatments. NPSFe already contained some P and thus required less P supplementation from TSP to meet the uniform P application rate. At the 85, 128, 170, and 255 kg N ha^{-1} rates, NPSFe supplied 23.8%, 35.8%, 47.6%, and 71.4% of the uniform P rate, respectively. Potassium and Zn were applied as KCl (0-0-60) and $ZnO/ZnSO_4$ (36% Zn, 9% S), respectively, for ammonium sulfate, urea, and NPSFe treatments.

The briquettes were unique in that they were manufactured from already commercially available fertilizers through a fertilizer briquetter machine developed by the IFDC. The briquetter machine allows the manufacturer to manipulate a fertilizer's guaranteed analysis to suit specific needs. In the case of this study, the briquettes were created by the IFDC and contained the appropriate mixture of nutrients so as to supply all the P, K, and Zn uniform rates while also applying the different N application rates according to the subplot treatment requirements. The S rate supplied from the briquettes was 2.46 kg S ha^{-1} at N rates above 0 kg N ha^{-1} (Table 1). This occurred because the S in the briquettes was supplied by $ZnSO_4$ (17.5% S) not $ZnO/ZnSO_4$ (9% S). The N, P, K, and Zn mineral sources used in the briquettes were urea, diammonium phosphate, potassium chloride, and zinc sulfate. More detailed crop and soil management practices are available in Winings et al. (2017) and Agyin-Birikorang et al. (2018).

Sampling and Measurements

Soil sampling was conducted in spring prior to treatment initiation at Jackson and Grand Junction, and after corn harvest in the fall each year using a two-centimeter-diameter soil probe. Ten random soil cores per split plot were collected at a 0-15 cm depth and mixed to create a single composite soil sample per split plot. Each sample was allowed to air-dry before being ground fine enough to pass through a 2-mm sieve using a Quaker City Mill model 4-E (The Staub Co., Philadelphia, PA), and then the sample was thoroughly mixed. Analyses conducted on each sample at the IFDC Soil Testing Laboratory were KCl extractable NH_4^+-N and NO_3^--N, extractable (Bray 1) P, SO_4^{2-}-S, and organic C.

Statistical Analyses

Analysis of variance (ANOVA) was conducted in a split plot randomized complete block design using the mixed model macro (%MMAOV) in SAS version 9.3 (SAS Institute, Cary, NC). The four fertilizer treatment types were whole plots and were treated as a fixed experimental factor; blocks were treated as a random factor. The four N application rates were subplots and were randomized within each whole plot. In JA1213, year and location were also treated as fixed experimental factors. For the soil analysis, post-harvest soil samples were analyzed after being adjusted for pre-treatment soil nutrient content. The post-ANOVA analysis method used was mean separation by Fisher's protected least significant difference (LSD). Probability values less than 0.05 for all analyses were designated as statistically significant.

RESULTS AND DISCUSSION

Weather conditions throughout the duration of this study varied considerably, most particularly, monthly precipitation averages (Figure 1). 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 Grand Junction in 2013, the average monthly precipitation was a little more moderate at 369.3 mm between the same time period. In sharp contrast, in 2012 both Jackson and Grand Junction 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 Grand Junction 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 Grand Junction in 2013 were much drier (111.0, 170.2, and 166.4 mm, respectively) during the same time period.

Average monthly temperatures also varied across location-years (Figure 2). In general, 2013 was a cooler year compared to 2011 and 2012 particularly during the spring months of March, April, and May. Temperatures in 2012 were as much as 5.6 to 8.3 ^{o}C warmer during that same time period. 2011 and 2012 were both approximately 3.3 ^{o}C warmer than 2013 during the whole month of July. Temperatures from August to the end of the growing season, however, were more similar across location-years.

Figure 1. Average monthly precipitation during the duration of this study.

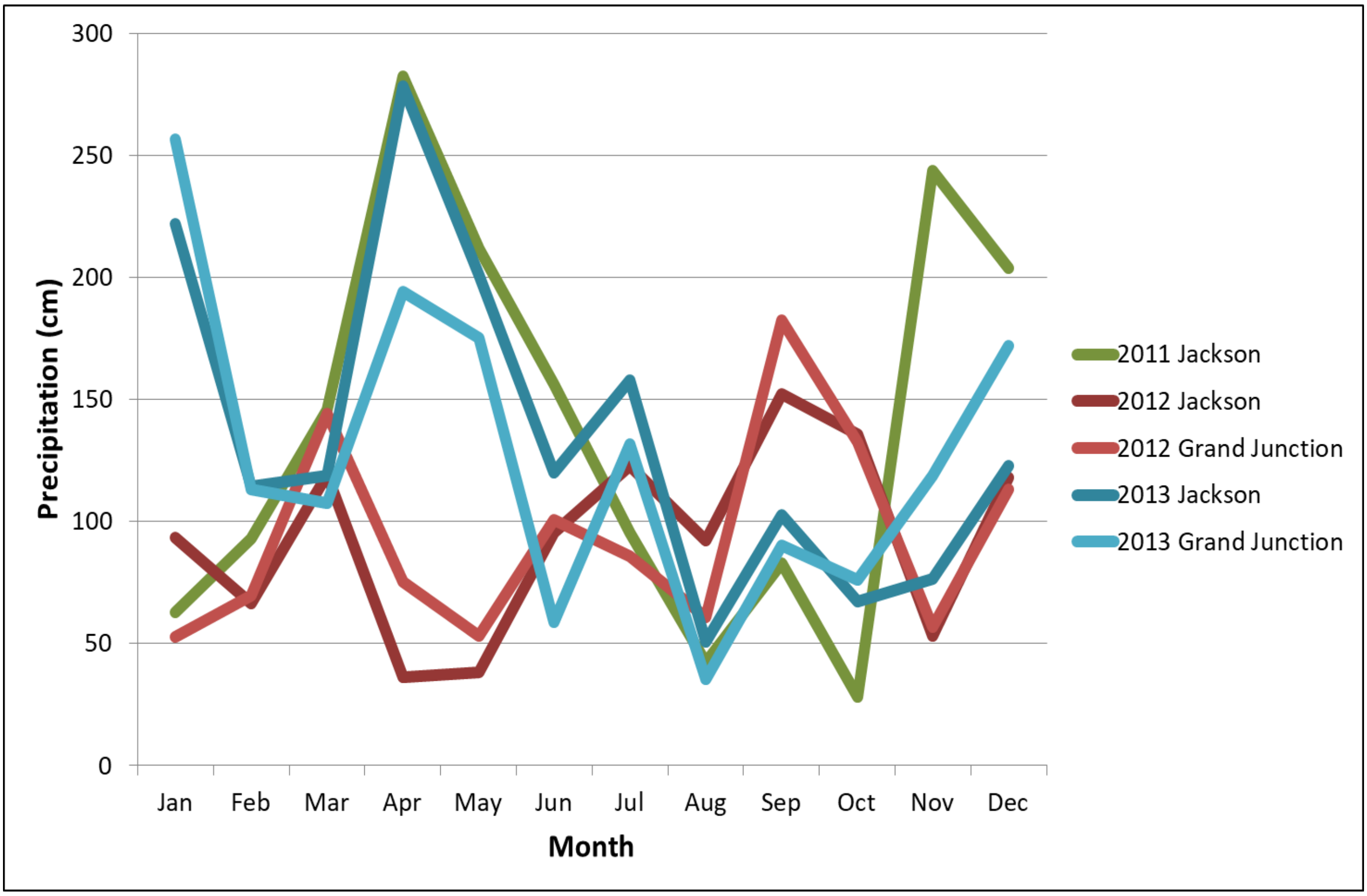
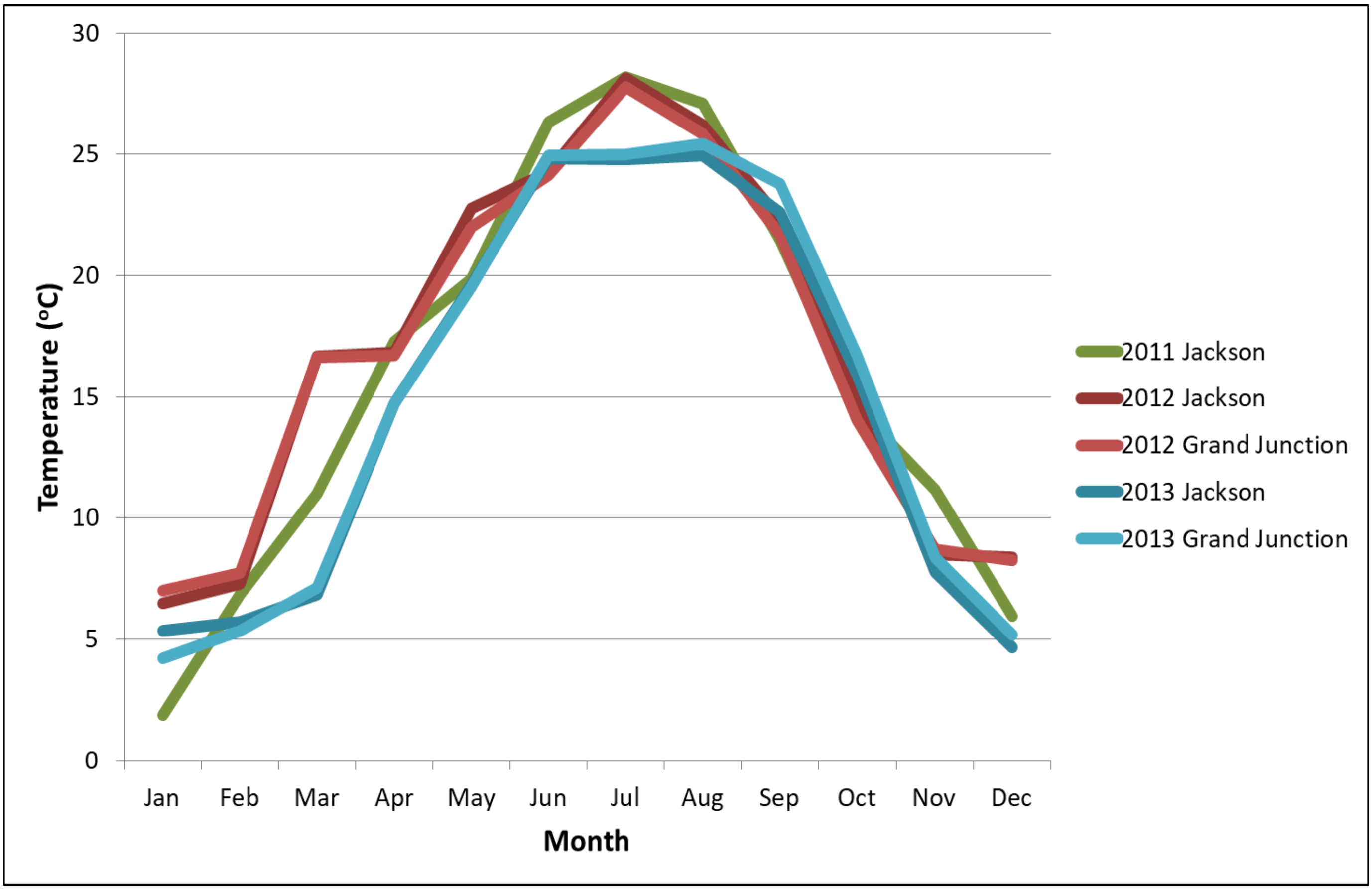


Figure 2. Average monthly temperatures during the duration of this study.



Phosphorus

There was a significant fertilizer type by N rate interaction effect on soil P concentrations in both J11 and JA1213 (Table 3). In J11, at the 85 and 255 kg N ha^{-1} rates, there was no difference between the fertilizer types in soil P concentrations. At the 170 kg N ha^{-1} rate, however, NPSFe, briquettes, and urea resulted in higher soil P concentrations than ammonium sulfate. In JA1213, the results were more confounded. At the 0 kg N ha^{-1} rate, soil P did not differ among the four fertilizer types. However, at the 85 and 128 kg N ha^{-1} rates, the briquettes had higher soil P concentrations than ammonium sulfate and urea. At the highest N rate of 255 kg N ha^{-1}, NPSFe and the briquettes were similar to ammonium sulfate and urea in post-harvest soil P levels. That NPSFe as a biosolid enhanced fertilizer did not increase soil P concentrations above all the other fertilizers may be an advantage, however because the N:P ratio of many biosolids is considerably lower than what is commonly taken up by plants thus creating oversupplied P with time (Elliot and O'Connor, 2007; O'Connor et al., 2005; Singh et al, 2012).

In JA1213 there was also a strongly significant year by fertilizer interactive effect on P soil concentrations. In 2012, the briquettes resulted in higher soil P concentrations than ammonium sulfate and urea (Table 4). In 2013, NPSFe had higher soil P concentrations than the briquettes and ammonium sulfate.

Overall, the effects of NPSFe and briquettes on soil post-harvest P after corn harvest were affected by N rates and years. Our results suggest NPSFe is sometimes lower than the other fertilizer types in post-harvest soil P fertility. That NPSFe did not excel in P soil concentrations is in contrast to Edmeades' findings in which organically fertilized soils were more P enriched than mineral fertilized soils (Edmeades, 2003). Indeed, other studies conducted on biosolid use as soil amendments found soil P availability to be greater with biosolid use (Cortellini et al., 1996; Huma, 1997; Jamil et al., 2006; Mantovi et al., 2005)

Nitrate-N

As with soil P concentrations, soil NO_3^--N concentrations after corn harvest experienced fertilizer type by N rate interactive effects in both J11 and JA1213 (Table 3). In J11 at the lowest N rate, fertilizer types did not differ in soil NO_3^--N concentrations. At the 170 and 255 kg N ha^{-1} rates, however, urea produced greater soil NO_3^--N concentrations than NPSFe and the briquettes. The briquettes had the lowest soil NO_3^--N levels at the 255 kg N ha^{-1} N rate. In JA1213, the differences between fertilizer types by N rate were less prominent. For example, at the 85 and 170 kg N ha^{-1} rates, NPSFe and the briquettes were fairly similar to ammonium sulfate and urea in soil NO_3^--N. At 128 kg N ha^{-1} rate, however, urea had higher soil NO_3^--N concentrations than NPSFe and the briquettes.

In JA1213 there were also significant year by fertilizer type and location by fertilizer type interactive effects on soil NO_3^--N concentrations (Table 4). In 2012, there were no differences in soil NO_3^--N concentrations among the fertilizer types. In 2013, however, urea had higher soil NO_3^--N levels than the briquettes and ammonium sulfate, and NPSFe had higher soil NO_3^--N concentrations than ammonium sulfate. At Jackson, NPSFe had less soil NO_3^--N than urea. At Grand Junction, however, no differences in soil NO_3^--N concentrations were observed among the fertilizer types.

In summary, the effects of NPSFe and the briquettes on post-harvest soil NO_3^--N after corn harvest were affected by N application rates, years, and locations. After corn harvest, soil NO_3^--N concentrations were generally lower with NPSFe and the briquettes than urea. Singh et al. (2012) found that biosolid enhanced fertilizers had delayed nitrification and significantly less NO_3^--N leaching than urea. That NPSFe in our study had less soil NO_3^--N concentrations than urea may also be an indication of delayed nitrification and thus greater N use efficiency by the plant. In J11, the briquettes generally produced lower soil NO_3^--N concentrations at the two highest N rates than the other fertilizer types, and in JA1213 NPSFe and the briquettes likewise produced lower soil NO_3^--N concentrations at the 128 kg N ha^{-1} rate than urea. This seems to suggest that the N in NPSFe and the briquettes nitrifies more slowly than urea which may lend itself to greater N use efficiency. Khalil et al. (2011) reported soil N to be much lower under urea super granules than surface applied prilled urea. They likewise found large soil reserves of fertilizer N at harvest from prilled urea, which was subject to loss and poor recovery by succeeding crops.

Ammonium-N

In J11, only N rates had a significant impact on soil NH_4^+-N concentrations (Table 2). The 170 kg N ha^{-1} rate resulted in higher soil NH_4^+-N concentrations than the other N rates which were all similar. It is interesting that the highest N rate was similar to the lowest two N rates in soil NH_4^+-N levels after corn harvest.

Table 2. Means of soil nutrient concentrations in the 0-15 cm depth for fertilizer types and N rates at Jackson and Grand Junction during 2011 to 2013.

	P	NO_3^--N	NH_4^+-N	SO_4^{2-}-S	Organic C
	.... mg kg^{-1}				g kg^{-1}
J11					
Fertilizer Type					
NPSFe	26.37a†	7.40bc	3.48a	3.64a	10.51a
NPKZn Briquettes	27.46a	5.19c	3.47a	3.29ab	9.70b
Ammonium Sulfate	23.01b	9.98ab	3.79a	3.68a	8.97c
Urea	26.67a	13.97a	3.81a	3.00b	9.44bc
N Rate (kg N ha^{-1})					
0	25.99a	4.50c	3.60b	3.15b	9.55a
85	25.01a	5.65c	3.43b	3.26ab	9.56a
170	26.60a	10.62b	4.19a	3.53ab	9.45a
255	25.90a	19.58a	3.33b	3.65a	10.05a
JA1213					
Fertilizer Type					
NPSFe	15.19a	0.76ab	1.87a	2.40a	12.67a
NPKZn Briquettes	12.86a	0.62c	1.24b	2.15b	10.66b
Ammonium Sulfate	13.22a	0.70bc	1.06c	2.70a	9.39c
Urea	13.74a	0.82a	2.00a	2.07b	9.87c
N Rate (kg N ha^{-1})					
0	16.51a	0.72b	0.72c	2.58a	8.67c
85	14.72b	0.70b	1.33b	2.50a	10.72b
128	13.26c	0.92a	2.20a	2.20b	11.00b
170	11.01d	0.59c	2.37a	2.03c	12.19a

†, means in each column within the fertilizer type or N rate treatments in the J11 or JA1213 dataset followed by the same letter are not significantly different at P = 0.05 according to the Fisher's protected LSD.

In JA1213, there was a strong fertilizer type by N rate interactive effect on soil NH_4^+-N concentrations (Table 3). At the 0 kg N ha^{-1} rate, NPSFe, the briquettes, and ammonium sulfate had higher soil NH_4^+-N concentrations than the urea. At the 85 kg N ha^{-1} rate, urea had higher soil NH_4^+-N levels than the other fertilizers followed by the briquettes and NPSFe which had higher soil NH_4^+-N than ammonium sulfate. At the 128 and 170 kg N ha^{-1} N rates, NPSFe and urea produced greater soil NH_4^+-N concentrations than the briquettes and ammonium sulfate.

Table 3. Interaction means of soil nutrient concentrations in the 0-15 cm depth for fertilizer types by N rates at Jackson and Grand Junction during 2011 to 2013.*

		P	NO_3^--N	NH_4^+-N	SO_4^{2-}-S	Organic C
		·············· mg kg^{-1} ··············				g kg^{-1}
J11						
N Rate (kg N ha^{-1})	**Fertilizer Type**					
0	NPSFe	24.37bc†	4.07a	—	3.37b	—
	NPKZn Briquettes	31.77a	4.47a	—	4.22a	—
	Ammonium Sulfate	19.33c	4.79a	—	3.45b	—
	Urea	28.50ab	3.92a	—	3.70ab	—
85	NPSFe	28.17a	3.95b	—	3.91a	—
	NPKZn Briquettes	24.72a	5.34ab	—	3.43ab	—
	Ammonium Sulfate	22.55a	4.93ab	—	3.66a	—
	Urea	24.60a	9.20a	—	3.35b	—
170	NPSFe	27.86a	9.14bc	—	4.28a	—
	NPKZn Briquettes	27.86a	6.20c	—	3.85b	—
	Ammonium Sulfate	21.52b	18.70ab	—	2.74b	—
	Urea	29.18a	25.62a	—	3.80b	—
255	NPSFe	25.07a	26.79b	—	3.95b	—
	NPKZn Briquettes	25.50a	6.12c	—	3.54c	—
	Ammonium Sulfate	28.63a	31.07ab	—	6.46a	—
	Urea	24.39a	48.63a	—	3.38c	—
	LSD††	5.48	16.54		0.24	
JA1213						
N Rate (kg N ha^{-1})	**Fertilizer Type**					
0	NPSFe	18.61a	1.44b	1.54a	2.89a	8.03b
	NPKZn Briquettes	22.67a	1.37b	1.56a	2.50ab	9.36a
	Ammonium Sulfate	18.80a	1.32b	1.75a	2.51a	8.65ab
	Urea	17.90a	1.57a	1.52b	2.42b	8.65ab
85	NPSFe	19.08ab	1.38ab	1.80bc	2.71a	12.65a
	NPKZn Briquettes	24.29a	1.57a	2.15b	2.46bc	10.67b
	Ammonium Sulfate	14.44b	1.26b	1.71c	2.58ab	9.50c
	Urea	16.42b	1.41ab	3.02a	2.22c	10.08bc
128	NPSFe	18.35ab	1.37c	3.39a	2.25a	13.75a
	NPKZn Briquettes	23.23a	1.54bc	2.69b	1.98b	11.48b
	Ammonium Sulfate	15.32b	1.60ab	2.18b	2.70a	8.53d
	Urea	16.93b	1.79a	3.29a	1.89b	10.22c
170	NPSFe	13.52b	1.12ab	4.15a	1.75b	16.24a
	NPKZn Briquettes	19.23a	1.09b	3.16b	1.63b	11.15b
	Ammonium Sulfate	17.03a	1.19ab	1.82c	2.99a	10.86b
	Urea	15.10ab	1.27a	4.05a	1.75b	10.51b
	LSD	3.55	0.41	0.76	0.60	1.05

*, only significant interactive effects are reported.

†, means in each column within each N rate level in the J11 or JA1213 dataset followed by the same letter are not significantly different at P = 0.05 according to Fisher's protected LSD.

††LSD, least significant difference values across all means within each column.

In JA1213 there was also a very significant year by fertilizer type interactive effect and also a very significant location by fertilizer type interactive effect on soil NH_4^+-N concentrations (Table 4). In 2012, NPSFe and the briquettes were similar to ammonium sulfate and urea in soil NH_4^+-N levels. In 2013, however, NPSFe and urea produced greater soil NH_4^+-N concentrations than the other fertilizer types. Within the location by fertilizer type interaction, at Jackson, NPSFe and urea had greater soil NH_4^+-N concentrations than the briquettes and ammonium sulfate. At Grand Junction, urea had greater soil NH_4^+-N concentrations than the other fertilizer types.

In general, NPSFe and urea sometimes had higher post-harvest soil NH_4^+-N than the briquettes and ammonium sulfate. The effects of NPSFe and the briquettes on soil post-harvest NH_4^+-N were influenced by N rates, years, and locations. Our results suggest that the briquettes may be more N efficient than NPSFe or urea because both had more post-harvest soil NH_4^+-N after harvest which is subject to loss or poor recovery by succeeding crops. That ammonium sulfate, like the briquettes, having lower soil NH_4^+-N is more likely due to ammonia volatilization, however. Vlek and Craswell (1979) found ammonia losses from ammonium sulfate to reach approximately 15% within three weeks of application on non-alkaline soils. Freney et al. (1981) reported 7% N losses from ammonia volatilization within 7 days of ammonium sulfate application. Fenn and Kissel (1973) compared different surface applied ammonium salt fertilizers and found that within 100 hours of application ammonium sulfate had lost 54% of its N to ammonia volatilization.

Sulfate-S

In both J11 and JA1213, there was a significant fertilizer type by N rate interactive effect on soil SO_4^{2-}-S concentrations (Table 3). In J11 at the 85 kg N ha^{-1} rate, NPSFe and ammonium sulfate had higher soil SO_4^{2-}-S concentrations than urea. At the 170 kg N ha^{-1} rate, NPSFe had higher SO_4^{2-}-S concentrations than the other fertilizer types. At the 255 kg N ha^{-1} rate, ammonium sulfate produced higher soil SO_4^{2-}-S concentrations than all the other fertilizer types and NPSFe produced higher soil SO_4^{2-}-S concentrations than the briquettes and urea.

In JA1213, NPSFe had similar soil SO_4^{2-}-S concentrations as ammonium sulfate at the 85 kg N ha^{-1} rate. At the 128 kg N ha^{-1} rate, NPSFe and ammonium sulfate had higher soil SO_4^{2-}-S than the briquettes and urea. At the 170 kg N ha^{-1} N rate, ammonium sulfate had higher soil SO_4^{2-}-S levels than the other fertilizer types.

Overall, the concentrations of post-harvest soil SO_4^{2-}-S were generally higher with NPSFe and ammonium sulfate than the briquettes and urea after corn harvest. The effects of NPSFe and ammonium sulfate on post-harvest soil SO_4^{2-}-S were affected by N rates, but were not influenced by years or locations. Our results suggest S in NPSFe and ammonium sulfate increase post-harvest soil S levels after corn harvest, particularly at higher application rates.

Organic Carbon

In J11, soil organic C concentration differed remarkably among fertilizer types (Table 2). NPSFe had higher soil organic C concentrations than the other fertilizer types. In JA1213 there was a highly significant fertilizer type by N rate interactive effect on soil organic C (Table 3). Aside from the control where all the fertilizer types were similar in organic C, NPSFe consistently had higher soil organic C concentrations than all the other fertilizer types at the 85, 128, and 170 kg N ha^{-1} rates. At the 128 kg N ha^{-1} rate, the briquettes had more post-harvest organic C than ammonium sulfate and urea.

In JA1213 there was a significant year by fertilizer type interactive effect on soil organic C concentration (Table 4). In both 2012 and 2013, NPSFe had greater soil organic C concentrations than all the other fertilizer types. Within 2013, briquettes produced greater soil organic C concentrations than ammonium sulfate and urea.

Overall, soil organic C concentrations were consistently higher with the NPSFe biofertilizer product than the other fertilizer treatments after corn harvest. The effects of NPSFe on soil organic C were affected by years and sometimes by N application rates. Our results suggest organic matter in the NPSFe biofertilizer product is available to enhance soil organic C levels after two to three years of application, particularly at higher application rates.

Table 4. Interaction means of soil nutrient concentrations in 0-15 cm depth for fertilizer types by years or locations from the JA1213 data set at Jackson and Grand Junction during 2012 to 2013.*

		Bray P	NO_3^--N	NH_4^+-N	Organic C
		………. mg kg^{-1} ……….			g kg^{-1}
Year	**Fertilizer Type**				
2012	Unity NPSFe	22.56ab†	2.37a	3.58ab	11.08a
	NPKZn Briquettes	29.82a	2.51a	3.66ab	9.74b
	Ammonium Sulfate	21.33b	2.43a	3.34b	8.82c
	Urea	21.63b	2.70a	4.36a	9.36bc
2013	Unity NPSFe	12.22a	0.29ab	1.86a	14.25a
	NPKZn Briquettes	14.89ab	0.28b	1.13b	11.58b
	Ammonium Sulfate	11.46c	0.26c	0.39c	9.96c
	Urea	11.55b	0.32a	1.58a	10.37c
	LSD††	2.77	0.39	0.59	0.82
Location	**Fertilizer Type**				
Jackson	Unity NPSFe	—	1.06b	2.23a	—
	NPKZn Briquettes	—	1.16ab	1.95b	—
	Ammonium Sulfate	—	1.06b	1.68b	—
	Urea	—	1.32a	2.10a	—
Grand Junction	Unity NPSFe	—	1.59a	3.21b	—
	NPKZn Briquettes	—	1.62a	2.84b	—
	Ammonium Sulfate	—	1.63a	2.05c	—
	Urea	—	1.70a	3.84a	—
	LSD		0.40	0.61	

*,only significant interactive effects are reported.

†, means in each column within each year or at each location in the JA1213 dataset followed by the same letter are not significantly different at P = 0.05 according to the Fisher's protected LSD.

††LSD, least significant difference values for means across years or locations within each column.

The soil data reveal that NPSFe does in fact impart significantly greater quantities of organic C into the 0-15 cm soil layer than the other fertilizer types in this study. This was true for both J11 and JA1213 and is a strong contrast to Gosling and Shepherd's (2005) findings in which soil organic C concentrations did not differ between farms that had been organically fertilized for 15 years versus conventionally fertilized farms. Other studies found increases in soil organic C with land applications of biosolids (Jamil et al., 2006; Mantovi et al., 2005). This is an important finding because higher concentrations of soil C have been associated with greater fertility benefits (Herencia et al., 2007) and improvement in soil physical characteristics such as superior soil aggregation and aeration (Dridi and Zerrouk, 2000). If the study had been allowed to continue perhaps NPSFe's organic C contribution would have amounted to greater corn mineral nutrition and productivity due to increased soil health.

CONCLUSIONS

Post-harvest soil NO_3^--N concentrations were generally lower with NPSFe and the briquettes than urea. This seems to suggest that the N in NPSFe and the briquettes nitrifies more slowly than urea which may lend itself to greater N use efficiency. NPSFe sometimes had higher post-harvest soil NH_4^+-N than the briquettes and ammonium sulfate. Our results suggest that the briquettes may be more N efficient than NPSFe or urea because both had more post-harvest soil NH_4^+-N after harvest which is subject to loss or poor recovery by succeeding crops. NPSFe sometimes tended to be higher than the other fertilizers in post-harvest soil P concentrations after corn harvest, thus the P provided by NPSFe may be less available than TSP. NPSFe and ammonium sulfate both increased post-harvest soil SO_4^{2-}-S levels compared to the briquettes and urea, particularly at higher application rates.

Post-harvest soil organic C levels were consistently highest under NPSFe. NPSFe consistently increases soil organic C levels, particularly at the higher N rates, within three years of experimentation. The fact that higher soil organic C levels is associated with greater soil health in scientific literature suggests that had the study continued longer, the greater organic C contributed to the soil by NPSFe may have translated into higher nutrient concentrations and grain quality of corn with time. Future research conducted for more than three years may be necessary to elucidate NPSFe's potential for greater soil health and thus plant mineral nutrition.

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REFERENCES

1. Agyin-Birikorang, S., J. Winings, X. Yin, U. Singh, and J. Sanabria. 2018. Field evaluation of agronomic effectiveness of multi-nutrient fertilizer briquettes for upland crop production. Nutrient Cycling in Agroecosystems 110:395–406.
2. Cortiellini, L., G. Toderi, G. Baldoni, and A. Nassisi. 1996. Effects on the content of organic matter, nitrogen, phosphorus, and heavy metals in soil and plants after application of compost and sewage sludge. The Science of Composting Part 1:457–468.
3. Dridi, B. and F. Zerrouk. 2000. Application of sewage sludges and properties of a soil in Algeria. Cahiers Agriculture 9:69–71.
4. Edmeades, D. C. 2003. The long-term effects of manures and fertilizers on soil productivity and quality: a review. Nutrient Cycling in Agroecosystems 66:165–180.
5. Elliott, H. A. and G. A. O'Connor. 2007. Phosphorus management for sustainable biosolids recycling in the United States. Soil Biology and Biochemistry 39:1318–1327.
6. Fenn, L. B. and D. E. Kissel. 1973. Ammonia volatilization from surface applications of ammonium compounds on calcareous soils: i. general theory. Soil Science Society of America Journal 37:855–859.
7. Freney, J. R., O. T. Denmead, I. Watanabe, and E. T. Craswell. 1981. Ammonia and nitrous oxide losses following applications of ammonium sulfate to flooded rice. Australian Journal of Agriculture Research 32:37–45.
8. Gosling, P. and M. Shepherd. 2005. Long-term changes in soil fertility in organic arable farming systems in England, with particular reference to phosphorus and potassium. Agriculture, Ecosystems & Environment 105:425–432.

9. Herencia, J. F., J. C. Ruiz-Porraas, S. Meleor, P. A. Garcia-Galavis, E. Morillo, and C. Maqueda. 2007. Comparison between organic and mineral fertilization and soil fertility levels, crop macronutrient concentrations, and yield. Agronomy Journal 99:973–983.
10. Huma, R. 1997. Effect of sewage sludge on grain yield of corn and wheat, soil fertility and heavy metals accumulation under rain fed condition. Master of Science Thesis, University of Arid Agriculture Rawalpindi, Pakistan pg:46.
11. Jamil, M., M. Qasim, and M. Umar. 2006. Utilization of sewage sludge as organic fertilizer in sustainable agriculture. Journal of Applied Sciences 6:531–535.
12. Khalil, M. I., U. Schmidhalter, R. Gutser, and H. Heuwinkel. 2011. Comparative efficacy of urea fertilization via supergranules versus prills on nitrogen distribution, yield response, and nitrogen use efficiency of spring wheat. Journal of Plant Nutrition 34:779–797.
13. Mantovi, P., G. Baldoni, and G. Toderi. 2005. Reuse of liquid, dewatered, and composted sewage sludge on agricultural land: effects of long-term application on soil and crop. Water Research 39:289–296.
14. Mengel, D. B., D. W. Nelson, and D. M. Huber. 1982. Placement of nitrogen fertilizers for no-till and conventional till corn. Agronomy Journal 74:515–518.
15. O'Connor, G. A., S. Brinton, and M. L. Silveira. 2005. Evaluation and selection of soil amendments for field testing to reduce P losses. Soil and Crop Science Society of Florida, Proceedings 64:22–34.
16. Pellegrino, J. L. and S. Lou. 2000. Energy and environmental profile of the U.S. chemical industry. Energetics, Inc. Columbia, MD and U.S. Department of Energy, Washington, D.C. http://www1.eere.energy.gov/manufacturing/resources/chemicals/pdfs/profile_chap5.pdf. Accessed on June 21, 2012.
17. Savant, N. K. and P. J. Stangel. 1990. Deep placement of urea supergranules in transplanted rice: principles and practices. Fertilizer Research 25:1–83.
18. Savant, N. K. and P. J. Stangel. 1998. Urea briquettes containing diammonium phosphate: a potential new NP fertilizer for transplanted rice. Nutrient Cycling in Agroecosystems 51:85–94.
19. Shober, A. L., R. C. Stehouwer, and K. E. Macneal. 2003. On-farm assessment of biosolids effects on soil and crop tissue quality. Journal of Environmental Quality 32:1873–1880.
20. Singh, U., J. Sanabria, E. R. Austin, and S. Agyin-Birikorang. 2012. Nitrogen transformation, ammonia volatilization loss, and nitrate leaching in organically enhanced nitrogen fertilizers relative to urea. Soil Science of America Journal 76:1842–1854.
21. Vlek, P. L. G. and E. T. Craswell. 1979. Effect of nitrogen source and management on ammonia volatilization losses from flooded rice-soil systems. Soil Science Society of America Journal 43:352–358.
22. Weber, D. 2013. Personal communication. CEO of Envirotech, LLC. Palisades, FL.
23. Wetselaar, R. 1985. Deep point-placed urea in a flooded soil: a mechanistic view. In: proceedings of the workshop on urea deep placement technology, Bogor, Indonesia pg:7–18. Special publication SP 6, IFDC Muscle Shoals, AL, USA.
24. Winings, J., X. Yin, S. Agyin-Birikorang, U. Singh, J. Sanabria, H. J. Savoy, F. L. Allen, and A. M. Saxton, 2017. Agronomic effectiveness of an organically enhanced nitrogen fertilizer. Nutrient Cycling in Agroecosystems 108:149–161.