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Evaluation of N sources, cover crops, and tillage systems for corn grown under organic management

Evaluación de fuentes de nitrógeno, cultivos de cubierta y formas de labranza para manejo orgánico de maíz

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Abstract. Public demand for healthier foods and more sustainable food systems in the U.S. has triggered market prices and production of organic alternatives of major crops such as corn (*Zea mays* L.). Two cover crops and their interactions with tillage systems, N sources and N rates were studied to evaluate the possibility of using these agronomic practices to facilitate growing corn under organic management in Kentucky. A split-split plot design in a RCBD with four replications was evaluated in three environments (SP08, UKR08, UKR09). The main plot treatments were cover crops [hairy vetch, HV (*Vicia villosa* Roth) and rye (*Secale cereale* L.)], the split plots were tillage systems [no-till (NT) and moldboard plow (MP)], and the split-split plots were the N treatment factorial combinations including two N sources [Louisville Green (LG) and Nature Safe (NF)] at four rates of N (45, 90, 135 and 180 kg N/ha plus a common control). In addition we conducted a laboratory study of nitrate release for the two selected N sources. Results showed the MP/HV combination resulted in the highest yields at all experimental sites followed by HV/NT. Ear leaf N and grain N content were higher under HV compared with rye at all sites. Nature Safe as N source, increased ear leaf N and grain N more than LG in all experimental sites, and increased yield at two of the three environments. Laboratory incubation studies showed that both N sources stopped mineralizing at 28 days after application, releasing, 55 kg N/ha on average. The MP/HV/NF treatment combination was the best management combination for organic corn production in the environments we studied.

Keywords: Organic corn; No-till; Rye; Hairy vetch; Louisville Green; Nature Safe.

Resumen. La demanda pública por alimentos más sanos y sistemas de producción más sustentables en los Estados Unidos ha disparado los precios de mercado y la producción de alternativas orgánicas de cultivos importantes como el maíz (*Zea mays* L.). Dos cultivos de cubierta invernal y sus interacciones con sistemas de labranza, fuentes de nitrógeno y diversas tasas de aplicación fueron estudiados para evaluar la posibilidad de usar estas prácticas agronómicas para el cultivo orgánico de maíz en Kentucky, Estados Unidos. Se utilizó un diseño de parcela dividida doble en bloques aleatorizados completos con cuatro réplicas en cada uno de tres ambientes (SP08, UKR08, UKR09). El tratamiento en la parcela principal fue cultivo de cubierta [vicia vellosa, HV (*Vicia villosa* Roth) y centeno, Rye (*Secale cereale* L.)]; en la primera parcela dividida se incorporó el tratamiento de sistema de labranza [labranza cero (NT) y arado de reja (MP)]; mientras que en la segunda parcela dividida se incorporó la combinación 2x4 factorial de los tratamientos de fuentes N [Louisville Green (LG) y Nature Safe (NF)] y sus tasas de aplicación (45, 90, 135 y 180 kg N/ha más un control común sin N). Al mismo tiempo se realizó un experimento de incubación en laboratorio para evaluar la liberación de nitratos por cada una de las fuentes nitrogenadas. Los resultados mostraron que la combinación de tratamientos MP/ HV produjo los mayores rendimientos en todos los ambientes seguida por la combinación HV/NT. El contenido de N en la hoja de la espiga y en grano fueron mayores con HV en comparación con Rye en todos los ambientes evaluados. La fuente nitrogenada NF aumentó el contenido de N en la hoja de la espiga y en el grano en comparación con LG en todos los ambientes, e incrementó el rendimiento en dos de los tres ambientes. La incubación en laboratorio mostró que ambas fuentes nitrogenadas cesaron su mineralización 28 días después de su aplicación, liberando, en promedio, 55 kg N/ha. La combinación de tratamientos MP/HV/NF fue el mejor conjunto de prácticas agronómicas para la producción orgánica de maíz and los ambientes estudiados.

Palabras clave: Maíz orgánico; Labranza cero; Centeno; Vicia vellosa; Louisville Green; Nature Safe.

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INTRODUCTION

Organic agriculture is defined by the USDA as "an ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony" (Gold, 2007). Public demand for healthier foods and more sustainable food systems in the U.S. has triggered market prices and production of organic alternatives of major crops such as corn and soybean (*Glycine max* L.) (Dimitri & Oberholtzer, 2005). Organic products earn higher prices resulting from higher production and distribution costs for organic goods along with the willingness of consumers to pay higher prices for such products (Batte et al., 2007). This price premium is one of the main reasons why the retail sales have grown from $3.5 billion in 1997 to $21.1 billion in 2008 (Demitri & Oberholtzer 2005). Moreover, the area devoted to organic corn production has increased from 31540 ha in 2000 to 78804 ha in 2008 (150%). In 2008, organic corn represented about 21.5% of the total organic US production (USDA-ERS, 2009). The top categories of organic products are produce and dairy products, yet the high demand has created shortages in the production chain (Demitri & Oberholtzer, 2009).

Organic corn is commonly grown with a heavy reliance on tillage for weed control (Posner, 2008; Cavigelli et al., 2009). However, the sustainability of these practices is in question, mainly due to their energy and labor requirements and the potential generation of soil compaction and erosion (Batey, 2009). Intensive tillage involves one or many of the following activities: plowing to bury residues, disking to break clods, harrowing or disking, and is carried out mainly to prepare the seed and root bed, control weeds and establish surface conditions that favor root development (Conservation Technology Information Center – CTIC, 2010). On the other hand, conservation tillage encompasses a series of practices that are intended to minimize residue incorporation to reduce soil erosion, leaving at least 30% of residue coverage at the time of planting. The main benefits of conservation tillage include reduced fuel consumption and labor cost, improved soil tilth and organic matter content, and enhanced moisture conservation while reducing erosion (CTIC, 2010). The least degree of soil disturbance under conservational tillage systems is obtained with NT production, which has proven to increase total C and N when compared with conventional tillage in many different environments (Blevins et al., 1983; Utomo et al., 1990; Handayani, 1996).

The normative for organic production prohibits the use of synthetic fertilizers for organic production (Gold, 2007). Therefore, farmers and researchers must use composts, cover crops and animal manure in order to provide enough nutrients for grain crops, especially high demanding N crops like corn. Cover crops have the potential to provide N while at the same time control erosion (Clark, 2007). A cover crop is one that is grown with the purpose of soil protection and to improve the soil quality between periods of regular crop production. Cover crops of rye and hairy vetch have been investigated for their effects on soil quality and the nutrient cycling potential (mainly N) in conventional corn production with a variety of results under till and no-till (NT) management (Bollero & Bullock, 1994; Villamil et al., 2006; Villamil et al., 2008; Mischler et al., 2010). However, there is scarce information of the performance of these cover crops for organic corn under Kentucky conditions. Cover crops are traditionally suppressed with herbicides (living mulches) or incorporated into the soil using additional tillage (green manure). The use of a roller-crimper (RC) machine to suppress cover crop growth is an alternative available to organic producers that decide to adopt NT management (Ashford & Reeves, 2003; Mischler et al., 2010).

Nitrogen availability is one of the main factors limiting corn production worldwide, and there is a crucial need to improve the efficiency of N fertilization strategies. In a conventional system where no legumes are included, the combination of N losses and lack of fertilization ensures a short supply of N that renders this system highly dependent upon N fertilization (Vitousek et al., 2002). The amount of N contribuited by hairy vetch and rye cover crops to a subsequent corn crop has been studied indirectly through their effects on yields. In a recent meta-analysis, Miguez and Bollero (2006) showed that legumes alone generated an additional 24% increase in the following corn crop; mixtures of winter cover crops (legumes and grasses) resulted in a 21.5% increase, while grasses showed a neutral effect on corn yield. Among the commercial N sources for organic agriculture, Nature Safe (NF10-2-8) produced by Griffin Industries (Cold Spring, KY), is a N source that is comprised of poultry by-products (feather meal, meat meal, bone meal and blood meal), sulfate of potash, yeast, sugars, carbohydrates and humus (Nature Safe 2010). This source is relatively new to the Kentucky market where there is a lack of scientific literature about their value in organic crop production.

With these issues in mind, the present paper addresses the possibility of growing organic corn in different environments across Kentucky under conventional and no-till systems, using two alternative cover crops, and two different sources of N, at different rates. The results of this study will provide relevant and needed recommendations to improve management and potentially increase adoption and profitability of organic corn production in Kentucky.

MATERIALS AND METHODS

Field sites. This investigation was conducted at two sites in 2008 and one site in 2009 for a total of three site-years.

In 2008 the sites were located at the University of Kentucky Spindletop Farm (SP), (38° 8' N, 84° 30' W), Fayette County, KY and at the University of Kentucky Research and Educational Center (UKR), (37° 06' N, 87° 52' W), Caldwell County, KY. In 2009 the experiment was conducted only at UKR in an adjacent field coordinates. The sites are hereby designated as SP08, UKR08, and UKR09, respectively. The soil series corresponding to SP08 was a Maury silt loam (fine, mixed, active, mesic, Typic Paleudalfs). Soil at the UKR08 and UKR09 sites was a Crider silt loam (fine-silty, mixed, active, mesic, Typic Paleudalfs) (USDA-NRCS, 2011). The preceding crop was tall fescue (*Festuca arundinacea* Schreb) for SP08 and orchard grass (*Dactylis glomerata* L.) for both UKR08 and UKR09.

Experimental design and crop management. The experimental design at each site was a split-split-plot design in a RCBD with four replications where the whole plot treatments were cover crops of hairy vetch (HV) and rye (Rye). The subplot size was 7.6 x 3.3 m. The split plots were tillage systems (no-till, NT and moldboard plow, MP), and the split-split plots were the N treatment factorial combinations including two N sources (Nature Safe, NF and Lousiville Green, LG) at four N rates (45, 90, 135 and 180 kg N/ha plus a common control). We tested the use of Louisville Green, a biosolid (Louisville and Jefferson County MSD 2010) that is not yet accepted for organic production but provides a useful reference. Reference soil fertility samples were taken from every whole plot (eight samples), on September 01, 2007 (SP08), on October 03, 2007 (UKR08) and on November 4, 2008 (UKR09). The samples were air dried and shipped for analysis to the University of Kentucky division of Regulatory Services located in Lexington, KY. Cover crops were planted using a Great Plains 605 NT Solid Stand drill on October 31, 2007 for SP08; October 15, 2007 for UKR08; and November 6, 2008 for UKR09. Seeding rates were 34 kg/ha for HV and 126 kg/ha for Rye. Suppression of cover crop growth in tilled subplots was performed first with a rotary mower prior to plowing. Suppression of cover crop growth in the NT subplots was performed with a front-mounted roller-crimper (RC) device fabricated by the University of Kentucky's farm shop based on plans provided by the Rodale Institute (The Rodale Institute, 2010). Tillage and planting operations for corn were carried out on a single day on June 13, 2008 for SP08; June 4, 2008 for UKR08; and June 2, 2009 for UKR09. Nitrogen amendments were applied at planting at the specified rates. The corn seed used was certified organic seed from Great Harvest Organics (hybrid 61K7). This is a 2400-2800 GDD hybrid adapted to maturity zones 6, 7, and 8. The planting rate was 74100 kernels/ha.

Plant sampling. Cover crop biomass was sampled just prior to corn planting, using a 0.25 m^2 square. Samples were dried for five days at 65 °C and were ground using a centrifugal mill (Thomas Model 4 Wiley Mill) and then finely ground using a Cyclone sample mill (Udy Corp. Model No. 3010-060). Samples were stored in sample bags and sub-samples were collected and analyzed for total N by the Kjeldahl method (Bradstreet, 1965). Total C analysis was carried out by the University of Kentucky division of Regulatory Services. Stand counts were determined by counting the number of plants in a 0.5-m length of the two central rows of each sub-sub plot. Counts were taken on July 2, 2008 for SP08; on June 25, 2008 for UKR08; and on June 18, 2009 for UKR09. Corn development was determined using a growing degree days (GDD) calculator (University of Kentucky Ag Weather Center 2010). Plant development was assessed by visual inspection using the guidelines established by Purdue University Cooperative Extension Service National Corn Handbook (Neild & Newman, 1990). Corn ear leaf N samples were collected on the central rows of every plot at silking. Three ear leaves were collected in from each sub-sub-plot on August 18, 2008 for SP08; August 6, 2008 for UKR08 and August 4, 2008 for UKR09. Ear leaf samples were dried for 5 days at 65 °C and then ground using a Cyclone sample mill (Udy Corp. Model No. 3010-060). From these samples, 0.01 g subsamples were analyzed for total N (Bradstreet, 1965). Corn was harvested on October 10, 2008 for SP08; September 26 and 27 for UKR08; and October 17, 2009 for UKR09. Corn yield was estimated by collecting samples from the two central rows of each sub-sub-plot. Samples were collected from a 4.57-m row length for SP08 and UKR08 and 3.0-m for UKR09. Whole ears were weighed and moisture content of the grain estimated from five ears for each sub-sub plots using a Dickey-John meter for UKR08 and SP08. At UKR09, five random ears from every plot were field weighed, then dried for 5 days at 60 °C and re-weighed in order to obtain moisture content at sampling time. Grain yield was based on a market standard of 15.5% moisture and expressed in Mg/ha. Grain N was determined from a sample of 5 dried ears for every sub-sub plot. Grain was ground using a coffee grinder and ground finer with a cyclone sample mill. Sub-samples were collected and total N was determined by the modified Kjeldahl method (Bradstreet, 1965).

Laboratory incubation study. Two methods of application for both N sources (surface applied or incorporated thoroughly) at three of the four different rates were included in this study. LG and NF fertilizers at rates of 45, 90, and 180 kg N/ha plus a common control 0 kg N/ha were converted to 100 g basis and incubated for 6 weeks in a Maury silt loam. Soil samples were collected on March 5, 2009 from the Spindletop research site. Samples were taken to a 10 cm depth using a soil auger from the central areas of the control plots and passed through a 2-mm sieve. A 100 g sample was placed into cores made of PVC and sealed in the bottom with two layers of plastic grid. Cores were incubated for seven days at 25 °C using a Lib-line Biotronette incubator (Model

681-853). After seven days of incubation, a solution of 100 ml 0.01 M $CaCl_2$ was passed through each core. Two 1 mL subsample were analyzed for NH_4^+ and NO_3^- content by the Greiss colorimetric method adapted to the microplate reader model (Crutchfield & Burton 1989). The rate of change for NH_4^+ and NO_3^- at each experimental time interval (7 days) was used to derive k reaction values. Differences in NH_4^+ and NO_3^- concentrations between the 0 kgN/ha and concentrations in samples receiving nitrogen were used to determine N release rates. The formula: $[A] - [A]_0 = -kt$ was used based on the zero order reaction obtained from the curves, where: $[A]_0$, initial concentration; $[A]$, final concentration; k, rate constant (mg inorganic-N /day); and t, time (days).

Statistical analysis. The variables analyzed for cover crops were biomass, total C (TC) and total N (TN). For corn the variables analyzed were: plant population (PP), grain yield (Y), ear leaf N (ELN) and grain N (GN). For the mineralization experiment the variable analyzed was soil NO_3^- released. All the statistical analyses were carried out using the PROC MIXED procedure from SAS 9.2 (SAS Institute, 2008) using preplanned estimates with alpha=0.1. Model residuals were used to check for the assumptions of normality and homogeneity of variances. The statistical analysis showed significance difference between locations and years therefore the years and locations were analyzed as fixed enviroments designated as SP08, UKR08 and UKR09. Results are presented separetely for each enviroment where only the significant effects and interactions are discussed.

RESULTS AND DISCUSSION

Weather conditions for the cover crop and corn growing seasons. Temperatures and precipitation during the cover crop (November to May) and subsequent corn (May to October) growing seasons are presented in Figure 1 along with their 30 year normal trend for the two locations closest to our research sites. Temperatures during the cover crop season were different during the two years of this study (Fig 1). Departures from normal trends were minimal and occurred in December for SP08 (2.1 °C above the 30 year normal) and on March and May for UKR08 and UKR09 (1.2 and 1.4 °C below the 30 year normal, respectively). During the corn growing season, UKR08 had warmer temperatures than the other two environments (Fig 1). Precipitation departures from normal trends were more noticeable. Comparatively, UKR08 had more precipitation than either SP08 or UKR09, especially during December (147 mm above normal). UKR09 was dry during March registering an average of 46 mm below the 30 year normal trend. The corn growing season was generally dry for 2008 and wet for 2009, with precipitation totals for SP08, UKR08, and UKR09 of 241, 252 and 800 mm, respectively. SP08 was driest during July, August and September with 57, 68, and 48 mm below the 30 year normal, respectively. The UKR08 experimental site was also dry during August (72 mm below normal) but with some rain during July (10 mm above normal) while UKR09 had a wet corn season with totals exceeding the normal trend during most of the growing season.

Soil fertility characteristics. The initial soil fertility conditions for all three experimental sites are shown in Table 1. Phosphorus levels at the SP08 test site were inherently high; these soils are classified as Maury silt loams (fine, mixed, active, mesic, Typic Paleudalfs), derived form from phosphatic limestone (USDA-NRCS 2010). The soil at both UKR08 and UKR09, is a Crider silt loam (fine-silty, mixed, active, mesic Typic Paleudalfs). Since the levels for P, K and Zn were sufficient in all environments, there was no need to apply fertilizer for these elements. Organic carbon levels were higher for SP08 than in UKR08 and UKR09 (Table 1).

Cover crop biomass production, C and N content. Significant differences in cover crop biomass production and C content were observed among sites (Table 2). Average biomass production for the three environments was 4.34 Mg/ha for HV and 9.50 Mg/ha for Rye. HV biomass contained 142 kg N/ha and Rye 60 kg N/ha at the time of corn planting. Rye biomass was greatest in UKR08 followed by SP08 and UKR09. Rye yielded 2.2 times more biomass than HV across all environments while HV yielded more biomass at SP08 than at the other two sites ($p<0.1$) (Fig 2). The C/N ratio is a key factor influencing the rate of decomposition and N release by the cover crop (Clark et al., 1994; Ruffo & Bollero, 2003; Crandall et al., 2005). Though C/N ratio was not influenced by environments, there were expected differences between cover crops with Rye having a five times higher C/N ratio than HV regardless of the site (Table 2). The interaction observed for C content among sites and cover crops mirrored differences in biomass production across sites. There was a 46% significantly greater C content for Rye in UKR08 than in either UKR09 or SP08, while HV had a greater C content in SP08 than in UKR09. Ebelhar et al. (1984) reported higher ranges of biomass and N content for HV than for Rye. In their study, cover crops were suppressed in mid-May and HV accumulated 5.1 Mg/ha with an average N content of 209 kg N/ha whereas Rye accumulated 3.4 Mg/ha with 36 kg N/ha.

Corn crop parameters. The effects of tillage, cover crop and N source were evaluated on plant population (PP) of corn, ear leaf N (ELN), grain N (GN) contents, and yield (Y) under the three environments (Table 3) Corn grain yields were significantly lower for all treatments at SP08 (Fig. 1). This result is attributed to weather conditions. Conditions at this site were dry during July and August 2008 (57 and 68 mm below normal, respectively). Corn PP was significantly affected in SP08 by the main effect of tillage ($p<0.01$) and cover crop ($p<0.1$). Condi-

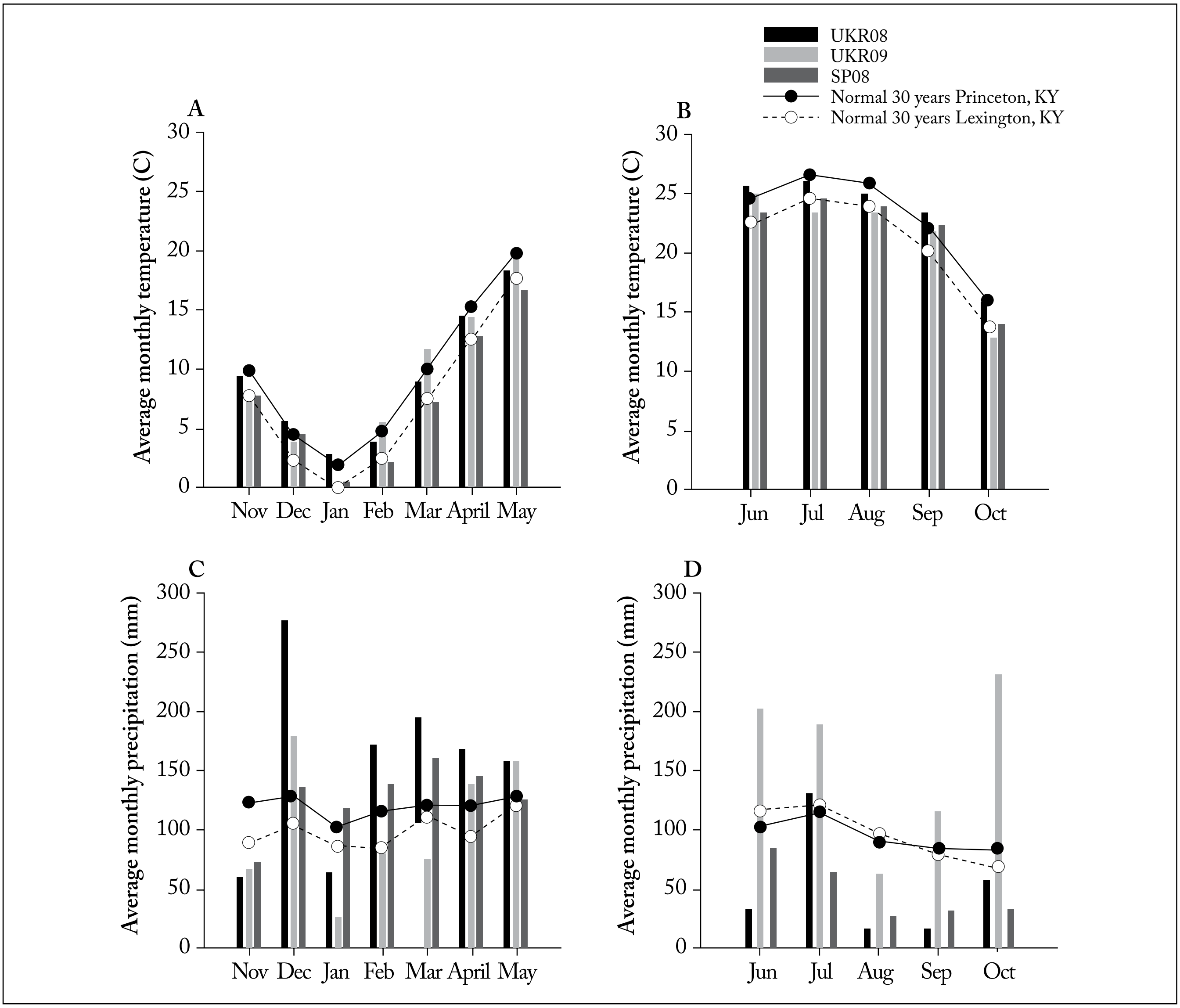

Fig. 1. Average temperature (A, B), precipitation (C, D) and their historical averages at the three studied environments of SP08 (Lexington, KY), UKR08 and UKR09 (Princeton, KY) during the cover crop (left panels) and corn (right panels) growing seasons.
Fig. 1. Temperaturas medias (A, B), precipitación (C, D) y sus promedios históricos respectivos para los sitios estudiados: SP08 (Lexington, KY), UKR08 y UKR09 (Princeton, KY) durante las estaciones de crecimiento de los cultivos de cubierta (paneles izquierdos) y del maíz (paneles derechos).

Table 1. Initial soil fertility conditions for the three environments under study, SP08, UKR08 and UKR09. Standard error in parenthesis (n=8).
Tabla 1. Condiciones iniciales de la fertilidad del suelo para los tres ambientes estudiados, SP08, UKR08 and UKR09. El error estándar se muestra entre paréntesis (n=8)..

Environment	pH	bpH	P	K	Ca	Mg	Zn	TN	TC	C/N
			kg/ha					g/kg		
SP08	6.16 (0.10)	6.50 (0.07)	713 (28)	606 (56)	4426 (158)	472 (50)	5.9 (0.7)	2.25 (0.06)	22.1 (0.9)	9.8 (0.2)
UKR08	5.90 (0.09)	6.80 (0.03)	33 (5)	355 (37)	3375 (241)	161 (22)	3.3 (0.3)	1.28 (0.04)	14.4 (1.4)	11.2 (0.8)
UKR09	6.57 (0.15)	7.00 (0.07)	98 (12)	385 (48)	3806 (323)	146 (16)	5.3 (0.2)	1.14 (0.07)	13.5 (0.9)	11.5 (0.5)

pH = soil pH; bpH = buffer soil pH; P = available P; TN = Total N; TC = Total C; C/N = carbon to nitrogen ratio.
pH = pH del suelo; bpH = pH buffer del suelo; P = P disponible; TN = N total; TC = C total; C/N = relación C/N.

Table 2. Rye and Hairy vetch (HV) cover crop biomass, carbon:nitrogen ratio (C/N) and plant C and N contents for the three studied environments: SP08, UKR08 and UKR09.
Tabla 2. Biomasa de los cultivos de cubierta de centeno (Rye) y vicia vellosa (HV), relación carbono:nitrógeno (C/N) y contenido de C y N vegetal para los tres ambientes estudiados: SP08, UKR08 and UKR09.

Factor	Levels	Biomass g/m^2	C/N	N content g/m^2	C content g/m^2
Environment	SP08	711 b	43.5 a	11.3 a	307 a
	UKR08	830 a	44.6 a	10.8 a	353 a
	UKR09	560 c	38.2 a	8.8 a	243 b
Cover crop	HV	434 b	13.7 b	14.2 b	185 b
	Rye	953 a	70.5 a	6.0 a	411 a

For a given factor and within columns, means followed by the same letter are not significantly different at α=0.1.
Para un factor dado y dentro de cada columna, promedios seguidos por la misma letra no son significativamente diferentes a α=0,1.

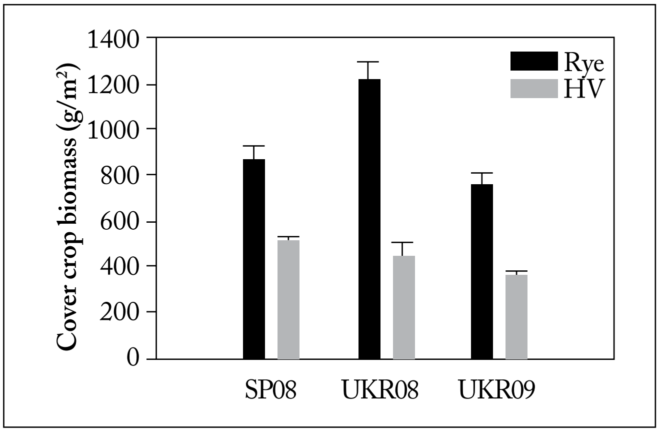

Fig. 2. Rye and hairy vetch (HV) cover crop biomass production (g/m^2) at the three studied environments: SP08, UKR08 and UKR09.
Fig. 2. Producción de biomasa (g/m^2) para los cultivos de cubierta de centeno (Rye) y vicia vellosa (HV) en cada uno de los ambientes bajo estudio: SP08, UKR08 y UKR09.

tions for emergence were poorer under NT compared to MP because of the greater residue biomass with Rye compared to HV, thus negatively affecting final PP. Ear leaf nitrogen (ELN) was affected in SP08 by the interaction cover crop x tillage x N rate (Fig 3). Corn following HV had an ELN of 22 g N/kg regardless of tillage method or N rate. After Rye, corn ELN was significantly greater under MP than NT. At UKR08, ELN was affected by the interaction cover crop x N source ($p<0.1$) in which ELN under HV was higher than Rye regardless of N source. However, ELN under Rye was higher when NF was applied compared with LG (Table 4). Grain N (GN, Table 3) was significantly affected by the interaction cover crop x tillage and cover crop x N rate at SP08; by the interaction cover crop x tillage x N source at UKR08; and by the interaction between cover crop x tillage at UKR09 (Table 3). At SP08, the interaction cover crop x tillage resulted in higher levels of GN following HV with 6% higher GN observed under NT compared to MP (Table 5). Corn following Rye, did not show significant differences in GN between tillage methods. The interaction between cover crop x N rate on GN at SP08 (Table 6) is on the result of a lack of response in HV plots to N rates compared to a strong response in corn following Rye. Rates 135 and 180 kg N/ha applied to corn following Rye resulted in significant increases in GN (Table 6). At UKR08, the interaction cover crop x tillage x N source, indicated that HV, as cover crop, led to higher GN than Rye. Rye/NF/MP treatment combination resulted in an increase of 8.4% in GN compared to the Rye/LG/MP treatment combination (Table 7). At UKR09, the interaction of cover crop x tillage showed that GN was significantly greater for the HV/NT treatment combination when compared to the HV/MP combination (~12.4%). However, GN following Rye was not influenced by tillage (Table 8).

Higher grain yields were obtained with the HV/MP treatment combination in all the environments followed by the HV/NT treatment combination in two out of three sites (Table 9). We attribute this result to the rapid N mineralization in the HV/MP treatment combination, previously observed by Utomo et al. (1990) in Kentucky for conventional corn. In 2008 and 2009, the statewide yield average was 8.55 and 10.4 Mg/ha, respectively, and our yields using the HV/MP combination approached conventional yields. Favorable conditions in 2009 resulted in record high corn yields for the state of Kentucky (USDA-NASS, 2010). There was a significant cover crop x tillage interaction for all three environments ($p<0.05$) affecting corn yield (Table 3). Average grain yields obtained with the HV/MP treatment combination were 2.77 Mg/ha, 7.76 Mg/ha and 9.47 Mg/ha for SP08, UKR08 and UKR09, respectively. At SP08, MP resulted in a higher grain yield than NT, regardless of cover crop (Table 9). However, under NT management, HV resulted in a significantly higher yield (114%) than Rye. There was an interaction tillage x N rate ($p<0.1$) at SP08 with NT corn having a significant response to N rate which was not observed under MP (Fig 4A). At UKR08 there was an interaction cover crop x tillage, in which yields of corn following HV were not influenced by tillage but were 17% higher under MP than under NT (Table 9) when corn followed Rye. At UKR09, the interaction of cover crop x tillage was present where the HV/MP

Table 3. Summary of ANOVA probability values for the main effects and interactions of cover crops, tillage, N source and N rate on corn variables at the three environments under study: SP08, UKR08, and UKR09.
Tabla 3. Resumen de valores de probabilidad de ANOVA para los factores principales e interacciones de cultivos de cubierta, laboreo del suelo, fuente de N y tasa de fertilización con N en variables de maíz y en los tres ambientes estudiados: SP08, UKR08, and UKR09.

Effects	SP08				UKR08				UKR09			
	PP Plants/ha	ELN g/kg	Y Mg/ha	GN g/kg	PP Plants/ha	ELN g/kg	Y Mg/ha	GN g/kg	PP Plants/ha	ELN g/kg	Y Mg/ha	GN g/kg
Cover crop	†	**	NS	**	NS	**	**	**	NS	**	**	**
Tillage	**	†	**	NS	NS	NS	NS	NS	NS	†	NS	*
N source	NS	†	NS	NS	NS	*	†	†	NS	†	*	NS
N rate	NS	**	†	**	NS	†	†	**	NS	**	**	NS
Cover crop x tillage	NS	**	*	*	NS	NS	*	NS	NS	NS	**	**
Cover crop x N source	NS	NS	NS	NS	NS	†	NS	†	NS	NS	NS	NS
Tillage x N source	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cover crop x N rate	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	†	NS
Tillage x N rate	NS	NS	†	NS	NS	NS	NS	NS	*	*	NS	NS
Cover crop x tillage x N rate	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N source x N rate	NS	†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cover crop x N source x N rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
Tillage x N source x N rate	NS	*	NS	NS	NS	NS	NS	*	NS	NS	NS	NS

PP = plant population; ELN = Ear leaf N; Y = Yield; GN = Grain N.
NS, not significant; † significant at p≤0.1; * significant at p≤0.05; ** significant at p≤0.01.
PP = población vegetal; ELN = N en la hoja bandera; Y = rendimiento; GN = N en granos.
NS, no significativo; † significativo a p≤0,1; * significativo a p≤0,05; ** significativo a p≤0,01.

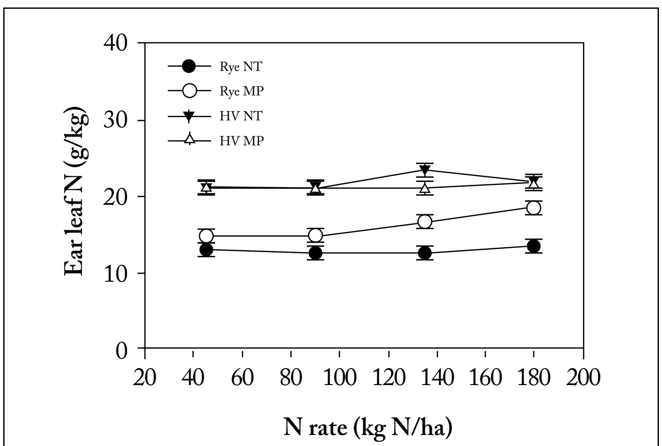

Fig. 3. Ear leaf N response to cover crop (Rye and HV, hairy vetch) x tillage (NT, no-till and MP, moldboard plow) x N rate (45, 90, 135, 180 kg N/ha) at SP08. Error bars represent standard error of the mean.
Fig. 3. Contenido de N en la hoja de la espiga (Ear leaf N) en respuesta a los tratamientos de cultivos de cubierta (Rye, centeno y HV, vicia vellosa) x labranza (NT, labranza zero y MP, arado de reja) x fertilización con N (45, 90, 135, 180 kg N/ha) en SP08. Barras de error representan el error estándar de los valores medios.

Table 4. Ear leaf N (ELN) at corn R1 stage of development affected by the interaction of cover crop (Rye and HV, hairy vetch) with N source (LG, Louisville Green and NF, Nature Safe) at UKR08.
Tabla 4. N de la hoja bandera (ELN) en el estadio R1 de desarrollo del maíz afectado por la interacción cultivo de cubierta (centeno y HV, vicia vellosa) con la fuente de N (LG, Louisville Green y NF, Nature Safe) en UKR08.

Cover crop	N source	ELN g/kg
Rye	LG	19.63 c
	NF	21.85 b
HV	LG	25.65 a
	NF	25.65 a

Means followed by the same letter are not significantly different at α=0.1.
Los promedios seguidos por la misma letra no son significativamente diferentes a α=0,1.

treatment combination had a significantly greater grain yield (39%) than HV/NT (Table 9). The interaction of cover crop x N rate was significant (p<0.1); grain yield was significantly greater

Table 5. Grain N (GN) affected by the interaction cover crop (Rye and HV, hairy vetch) with tillage (NT, no-till and MP, moldboard plow) at SP08 environment.
Tabla 5. N en el grano (GN) afectado por la interacción cultivo de cubierta (centeno y HV, vicia vellosa) con labranza (NT, labranza cero y MP, arado de reja) en el ambiente SP08.

Cover crop	Tillage	GN g/kg
Rye	NT	10.51 c
	MP	11.21 c
HV	NT	15.08 a
	MP	14.23 b

Means followed by the same letter are not significantly different at α=0.1.
Los promedios seguidos por la misma letra no son significativamente diferentes a α=0,1.

Table 6. Grain N (GN) affected by the interaction cover crop (Rye and HV, hairy vetch) with N rate at SP08 environment.
Tabla 6. N en el grano (GN) afectado por la interacción cultivo de cubierta (centeno y HV, vicia vellosa) con la tasa de aplicación de N en el ambiente SP08.

Cover crop	N rate kg N/ha	GN g/kg
Rye	45	10.07 d
	90	10.47 d
	135	11.11 c
	180	12.43 b
HV	45	14.71 a
	90	14.76 a
	135	14.53 a
	180	14.53 a

Means followed by the same letter are not significantly different at α=0.1.
Los promedios seguidos por la misma letra no son significativamente diferentes a α=0,1.

Table 7. Grain N (GN) affected by the interaction cover crop (Rye and HV, hairy vetch) with tillage (NT, no-till and MP, moldboard plow) and N source (LG, Louisville Green and NF, Nature Safe) at UKR08.
Tabla 7. N en el grano (GN) afectado por la interacción cultivo de cubierta (centeno y HV, vicia vellosa) con labranza (NT, labranza cero y MP, arado de reja) y fuente de N (LG, Louisville Green y NF, Nature Safe) en UKR08.

Cover crop	Tillage	N source	GN g/kg
Rye	NT	NF	10.80 c
		LG	10.37 cd
	MP	NF	10.70 c
		LG	9.87 d
HV	NT	NF	13.66 a
		LG	13.31 ab
	MP	NF	12.72 b
		LG	13.09 ab

Means followed by the same letter are not significantly different at α=0.1.
Los promedios seguidos por la misma letra no son significativamente diferentes a α=0,1.

Table 8. Grain N (GN) affected by the interaction cover crop (Rye and HV, hairy vetch) with tillage (NT, no-till and MP, moldboard plow) at UKR09.
Tabla 8. N en el grano (GN) afectado por la interacción cultivo de cubierta (centeno y HV, vicia vellosa) con la labranza (NT, labranza cero y MP, arado de reja) en UKR09.

Cover crop	Tillage	GN g/kg
Rye	NT	9.45 bc
	MP	9.31 c
HV	NT	10.11 b
	MP	11.36 a

Within columns, means followed by the same letter are not significantly different at α=0.1.
Dentro de cada columna, los promedios seguidos por la misma letra no son significativamente diferentes a α=0,1.

following HV than Rye but this difference disappeared at the high N rate (Fig 4B). Ebelhar et al. (1984) working at Spindletop, KY, during 1977 through 1981, found that the HV/NT treatment combination increased the levels of soil inorganic N from a steady state of 10 mg inorganic N/kg before planting to 40 mg N/kg 18 days after planting (DAP) and 25 mg N/kg at 37 DAP without any addition of fertilizer. When 100 kg N/ha was added, the amount of inorganic N doubled at 18 DAP, and steadily decreased to around 20 mg N/kg at 37 DAP.

Mineralization experiment. Results indicated that both LG and NF mineralized mostly as NO_3^- with relatively little evolution of NH_4^+ (data not shown). In general, the mineralization reached a maximum at 28 days after NF application and stayed nearly constant until the end of our incubation (56 days) (Fig. 5). Figure 5A shows surface application of NF at a rate of 180 kg N/ha generated a significantly greater amount of NO_3^- than all other treatments throughout the incubation period. However, when the sources were incorporated into the soil, LG at a rate of 90 kg N/ha released significantly more NO_3^- than all other treatment combinations (Fig. 5B).

Total inorganic N production was 25.6 mg N/kg soil with the LG treatment and 29.6 mg N/kg soil with the NF treatment. Figure 6 shows there was a significant interaction be-

Table 9. Corn grain yield (Mg/ha) response to cover crop (Rye and HV, hairy vetch) and tillage (NT, no-till and MP, moldboard plow) at the environmnets under study.

Tabla 9. Respuesta del rendimiento de granos de maíz (Mg/ha) al cultivo de cubierta (centeno y HV, vicia vellosa) y la labranza (NT, labranza cero y MP, arado de reja) en los ambientes estudiados.

Cover crop	Tillage	SP08	UKR08	UKR09
Rye	NT	0.95 c	5.47 c	6.15 bc
	MP	2.96 a	6.04 b	4.68 c
HV	NT	2.03 b	8.04 a	6.82 b
	MP	2.77 a	7.76 a	9.47 a

Within columns, means followed by the same letter are not significantly different at α=0.1.

Dentro de cada columna, los promedios seguidos por la misma letra no son significativamente diferentes a α=0,1.

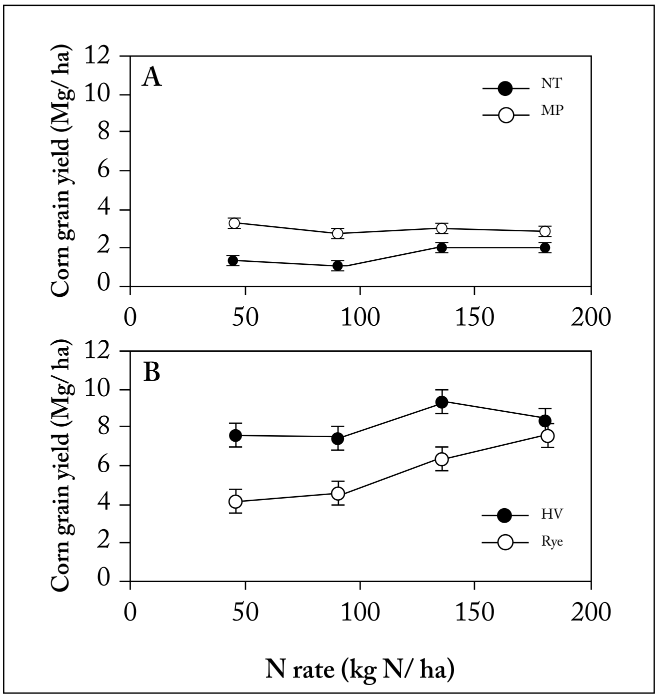

Fig. 4. Corn grain yield response to A) tillage (NT, no-till and MP, moldboard plow) and N rate at SP08 and B) cover crop (Rye and HV, hairy vetch) and N rate for UK09. Error bars represent standard error of the mean.

Fig. 4. Respuesta en el rendimiento en grano del maíz a los tratamientos de A) labranza (NT, labranza zero y MP, arado de reja) y fertilización con N (45, 90, 135, 180 kg N/ha) en SP08 y B) cultivos de cubierta (Rye, centeno y HV, vicia vellosa) y fertilización con N (45, 90, 135, 180 kg N/ha) en UK09. Barras de error representan el error estándar de los valores medios.

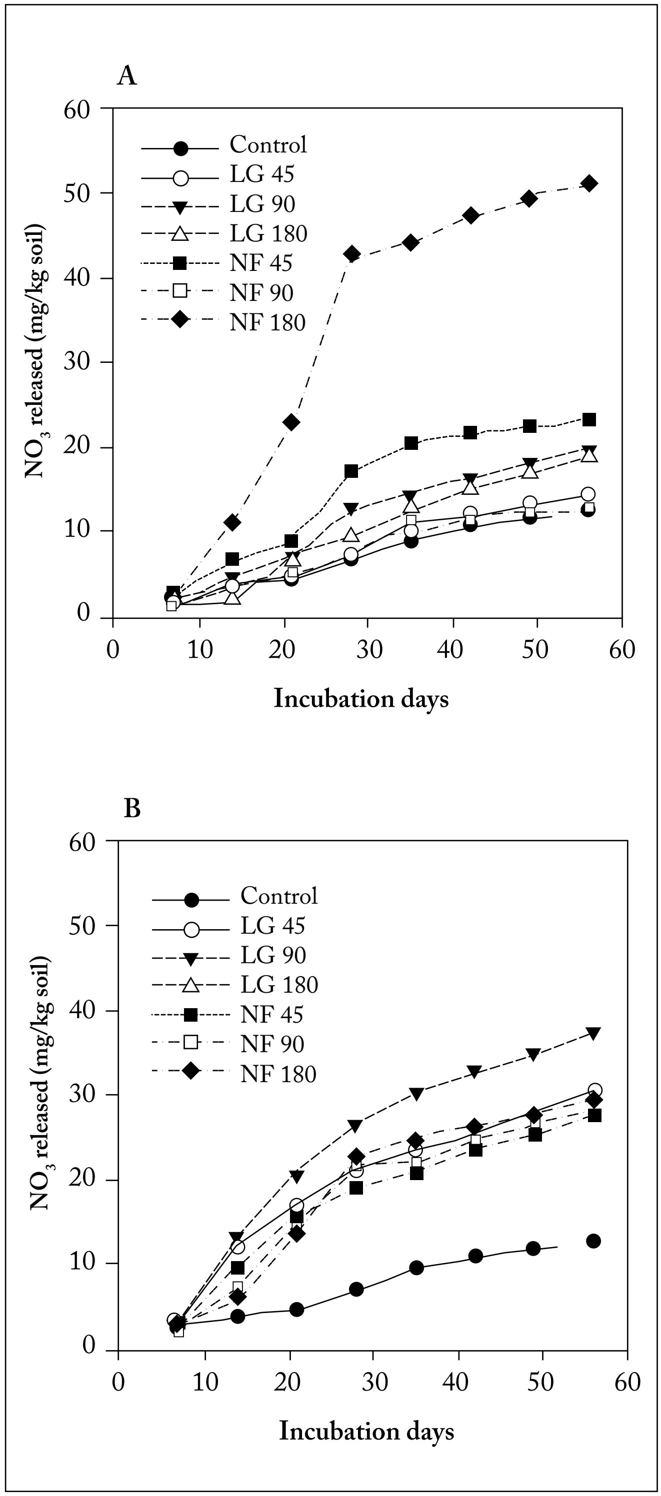

Fig. 5. NO_{3^-} released in the soil with A) surface application or B) incorporation of the N sources Louisville Green (LG) and Nature Safe (NF) at three N rates, 45, 90, and 180 kg N/ha.

Fig. 5. Cantidad de nitrato (NO_{3^-}) liberado en el suelo con A) aplicación superficial o B) incorporación de las fuentes de nitrógeno Louisville Green (LG) y Nature Safe (NF) a tres tasas de fertilización, 45, 90, y 180 kg N/ha.

tween method x N source x N rate (p<0.1) on the total amount of NO_3^- released in the soil. Surface application of NF at a rate of 180 kg N/ha generated a significantly greater amount of NO_3^- than all other treatments but LG incorporated at a

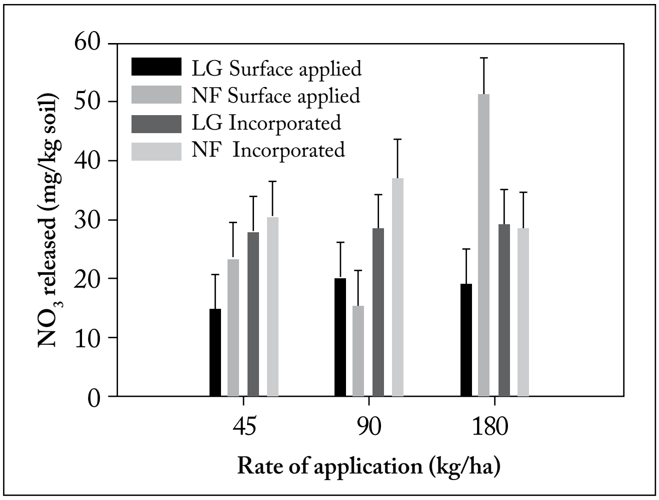

Fig. 6. Effect of method of application (Surface applied, Incorporated) and N source (LG, Louisville Green and NF, Nature Safe) at three different rates on the total NO_3- released in the soil after 56 days of aerobic incubation.

Fig. 6. Efecto del modo de aplicación (aplicación superficial o incorporada) y de la fuente de nitrógeno (LG, Louisville Green y NF, Nature Safe) a tres tasas de fertilización en el contenido total de nitratos liberados en el suelo luego de 56 días de incubación aeróbica.

rate of 90 kg N/ha (Fig. 6). For a corn crop, N should be available at or near planting and around the V6 growth stage after which N uptake increases rapidly (Abendroth et al., 2011). In our case, V6 occurred in SP08 at about 22 DAP (July 4) and in UKR08 and UKR09 around 19 DAP (June 21 and June 20, respectively). Application of NF or LG should then be recommended at planting to ensure full availability of N by V6. Total N mineralized by these sources at the studied rates (average 55 kg N/ha) would not be sufficient for a high yielding corn hybrid to reach its full potential.

CONCLUSIONS

Based on this experiment, it was possible to grow corn with agronomic practices accepted for organic production with relative high yields in two out of three environments using the HV/MP treatment combination (average 8.6 Mg/ha). The Rye/NT treatment combination resulted in the lowest grain yields across the 2008 environments when compared to the Rye/MP and HV/NT treatment combinations. Nevertheless, this yield disadvantage disappeared in wetter conditions such as those prevailing in UKR09. In general, there was little benefit of increasing ELN with N fertilization after HV but there was significant increase in ELN after Rye. The benefits of adding NF or LG sources for high yields seem inconsistent and need further research.

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