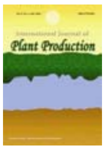

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Potential N mineralization and availability to irrigated maize in a calcareous soil amended with organic manures and urea under field conditions

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Abstract

Quantification of the Nitrogen (N)-supplying capacity of organic manures provides an important insight into more effective N management practices. The aims of this study were to determine the potential N mineralization of cow manure (CM), poultry manure (PM), urea fertilizer (UF) and the combined use of cow manure + urea fertilizer (CM + UF) for silage maize (*Zea mays* L.) in a calcareous soil under field conditions. Selected soil samples were collected after different N sources application, and mineral N (NO_3^--N and NH_4^+-N) was determined for a total of 110 days of field incubation, using the buried bag technique. Poultry manure-treated soils had significantly higher total N mineralization (244 kg ha^{-1}) than CM (109 kg ha^{-1}), UF (138 kg ha^{-1}) and CM + UF (141 kg ha^{-1}) treated soils. However, N availability was greater in UF (69%) and PM (61%) treated soils than that of CM + UF (47%) and CM (28%) fertilized soils. Shoot dry matter of maize and N uptake were considerably higher in PM treated soil than in UF, CM and CM + UF soils. Nevertheless, maize N recovery was significantly higher in urea soils (60%) than in PM (42%) and CM + UF (37%) soils followed by CM soil (15%). In conclusion, our data indicated that PM and the CM + UF that released N slowly resulted in high maize silage production, N uptake and N recovery following their application in these calcareous soils with low SOM content and N availability.

Keywords: N-supplying capacity; Cow manure; Poultry manure; Inorganic fertilizers; Silage maize; N uptake and recovery.

Introduction

In arid and semi-arid lands (collectively dryland areas where annual potential evapotranspiration exceeds precipitation), low soil organic matter (SOM) contents and water availability are two major constraints for the activity of soil microbial community with a consequence for sustainable plant growth and productivity (Li and Sarah, 2003; Conant et al., 2004; Bastida et al., 2006). Therefore, high inputs of external chemical fertilizers into nutrient deficient dryland soils are required to maintain soil fertility for crop production.

Chemical nitrogen (N) fertilizers including urea are the major inputs into arid and semi-arid soils for a reasonable yield production (Irshad et al., 2002; Raiesi, 2004; Zhang et al., 2008). The application of urea N fertilizers has, however, been reported to influence biologically mediated processes (Mahmood et al., 1997; Raiesi, 2004; Akiyama et al., 2004; Yan et al., 2007), which are important in N cycling and transformations (Paul and Beaucham, 1993; Paul and Beaucham, 1996; Sistani et al., 2007; Zhang et al., 2008). In dryland soils with low SOM contents, an increase in mineral N availability, especially urea, stimulates soil microbial activity and SOM mineralization, which would lead to SOM losses in the long-term (Mahmood et al., 1997; Raiesi, 2004). Excessive application of chemical N fertilizers can also result in N losses via leaching, de-nitrification and volatilization under certain conditions (Zhang et al., 2008; Akoumianakis et al., 2011). The loss of N fertilizers would undoubtedly increase the risk of environmental pollution, in addition to economic losses (Xing and Zhu, 2000; Araji et al., 2001; Akoumianakis et al., 2011; Tafte and Sepaskhah, 2012).

There are different options for the maintenance of soil quality and fertility, among which the application of organic manures could be an effective alternative to maintain an adequate input of organic matter into dryland soils (Williams, 1999; Barzegar et al., 2002; Min et al., 2003). The application of organic manures provide more advantages over mineral fertilizers because of improvements in soil structure, aggregate stability, soil nutrient exchange capacity, water holding capacity, soil bulk density, microbial biomass and activity, and crop yields (Haynes and Naidu, 1998; Barzegar et al., 2002; Manna et al., 2007). In addition, organic manures increase soil C and N pools by increasing protected SOM within aggregates (Williams, 1999; Judith et al., 2009).

Nitrogen mineralization rates and the total amount of soil N are two important indicators of N availability, because they regulate soil NH_4^+-N and NO_3^--N concentrations and the availability of inorganic N to plants (Gilmour et al., 2004; Eghball et al., 2002; Sistani et al., 2007). Research has shown that soil N mineralization and availability are affected by organic and inorganic fertilizers (Eneji et al., 2002; Azeez and Averbeke, 2010) and by the factors regulating microbial community and activity (Paul and Beauchamp, 1996; Mahmood et al., 1997; Eneji et al., 2002). Organic fertilizers provide a gradual N supply for a long period of time, which improves N use efficiency and reduces N leaching losses (Abbasi and Tahir, 2012). The application of organic manures and wastes from various resources often results in higher N mineralization rates and N availability for crop N uptake (Paul and Beauchamp, 1996; Irshad et al., 2002; Cordovil et al., 2007). However, the magnitude of N availability and the mineralization rate of manure organic N is mainly determined by the chemical composition of the organic manures being decomposed and the activity of the soil microorganism (Van Kessel et al., 2000; Van Kessel and Reeves, 2002). Previous reports show that cow manure N availability ranged from 0 to 50% of the initial organic N (Chae and Tabatabi, 1986), while 0-74% of the initial organic N in different poultry manures was mineralized over short- (Qafoku et al., 2001) and long-term (Preusch et al., 2002; Gilmour et al., 2004) incubations. Large differences in N contents, C/N ratios, water-soluble compounds and recalcitrant components of organic manures are responsible for the different N-mineralization rates (Sistani et al., 2007; Azeez and Averbeke, 2010). However, the chemical composition of manures varies with the age of the animal, the feed and feeding patterns, feed conversion efficiency, water intake, management system and sex (Chae and Tabatabi, 1986; Nahm, 2005; Azeez et al., 2009). This is perhaps, the reason for the wide variations in N availability among different types of animal manures. Manure N mineralization is also controlled by the chemical and physical conditions of the soil such as temperature, pH, water holding capacity, total N and organic C content (Nahm, 2005; Arslan et al., 2005; Sistani et al., 2007).

Previous works reported a relationship between plant N uptake from the manure organic N fractions and the potential N mineralization or N availability in organic manures and wastes (Whitehead et al., 1989; Chadwick et al., 2000; Cordovil et al., 2007). For example, Cordovil et al. (2007) showed that potentially mineralizable N from six organic wastes was correlated to N uptake by ryegrass and wheat. Salazar et al. (2005) found a large response of maize to manure application with higher dry matter and N uptake. However, Paul and Beauchamp (1993) reported the lack of maize response to manure N only in high fertile soils. These indicate that the N supply rates of organic manures are both manure and site specific in maize cropping systems, and may change with manure and soil type (Van Kessel and Reeves, 2002; Cordovil et al., 2007; Monaco et al., 2010). Therefore, the quantification of the N-supplying capacity of organic manures is essential to obtain optimum maize yields while minimizing possible N losses through nitrate leaching, de-nitrification and ammonium volatilization in dryland soils. The main objective of this study was to determine and compare the influence of two organic manures (i.e., cow and poultry manures), urea and cow manure + urea applications on soil net N mineralization, and ultimately on N availability to irrigated maize in a calcareous soil under field conditions. Our results should further help in developing a fertilizer management strategy based on the selection of fertilizers for maize production in the study area.

Materials and Methods

Study site description

A field experiment was conducted on an arid calcareous clay loam soil in 2009 at the Research Farm of Shahrekord University (50˚ 49́ E, 32˚ 21́ N, 2050 m above sea level). The mean annual rainfall is 334 mm and annual temperature is 10.8 ^{o}C. Soils of the area are calcareous with more than 30% equivalent calcium carbonate in the surface layer, which have developed in limestone. The study soil has never fertilized with organic manures. Soil samples (0-30 cm depth) were obtained and analyzed for some characteristics before the initiation of the experiment (Table 1). Soil texture, pH (pH H_2O in 1:2.5 ratio), electrical conductivity (EC), organic carbon (OC) (the Walkley-Black method), total nitrogen (the Kejldahl method), extractable P (the Olsen's method), available K and $CaCO_3$ contents were determined, following procedures described in Carter and Gregorich (2008). Cow and poultry manures were obtained from dairy and poultry farms of Shahrekord University. The manures were made up of the faces and urine mixed with different proportions of straw and sawdust as bedding materials. All manure samples were air-dried and ground to 1 mm for analysis. For manures, EC, OC, total nitrogen, P and K were measured (Table 2).

Table 1. Some physical and chemical properties of the study soil (0-30 cm).

Property	value
Sand (%)	24
Silt (%)	40
Clay (%)	36
Texture	Clay loam
Bulk density (g cm^{-3})	1.25
pH	7.10
EC (dSm^{-1})	0.48
$CaCO_3$ (%)	33.5
Organic C (%)	0.48
Total N (%)	0.06
C/N	8.0
Initial NO_3-N (mg kg^{-1})	0.172
Initial NH_4-N (mg kg^{-1})	0.321
Inorganic N (kg ha^{-1})	1.85
Available P (mg kg^{-1})	11.0
Available K (mg kg^{-1})	278

Table 2. Mean values of nutrient contents, organic C and EC in the poultry and cow manures used in this study.

Property	Poultry manure (PM)	Cow manure (CM)
Total N (%)	3.0	0.98
Organic C (%)	36.6	20.1
C/N	12.2	20.5
P_2O_5 (%)	2.40	0.23
K_2O (%)	1.30	1.10
EC (dS m^{-1})	12.7	7.32

Experimental setup

The experimental design was randomized complete block design, using five N fertilizer treatments with four replications. The N fertilizer treatments included in the present study were control soils without fertilizer (C), urea (UF, 200 kg N ha^{-1}), cow manure (CM, 400 kg N ha^{-1}), cow manure + urea (CM + UF, 200 kg N ha^{-1} from cow manure and 100 kg N ha^{-1} from urea) and poultry manure (PM, 400 kg N ha^{-1}) on a soil dry weight basis. The mineral N was applied as urea ($CO(NH_2)_2$; 46% N), the predominant N fertilizer used in the study area. Application of 13.33 and 40.82 Mg ha^{-1} of poultry and cow manures provided 200 and kg N ha^{-1} assuming 50% mineralization of poultry and cow manures, respectively (Adeli et al., 2005).

Potassium (K) fertilizer was not applied because the study soil contained an initial K level of 278 mg kg^{-1} (Table 1). Phosphorus (P) fertilizer (triple superphosphate) was applied at a rate equivalent to the total P added by poultry manure. The urea-N was split into three applications in all plots during the vegetative stage. One-third of the urea-N was applied at planting, one-third as a side-dress application when plants were 2-3 weeks old, and one-third at tasselling. Organic manures and P fertilizer were incorporated into the soil immediately after application and before planting. The study soil was under fallow in the year before and was cropped with irrigated silage maize (*Zea mays* L.). Twenty plots (7×4 m) were arranged in 6 rows with a distance of 60 cm. The distance between plots was 2 m, and for each plot two rows were set up as buffer zone. Three silage maize (Single Cross 704) seeds were sown by hand per enclosure in the center of each row at a density of 140000 plants ha^{-1} and thinned to one plant per enclosure at the 3-4^{th} leaf stage after 3 weeks. The maize was harvested by cutting shoots at the soil surface for shoot dry weights and N content. Subsamples were taken from all shoot samples and ground with mill (< 0.5 mm mesh). Plant shoot samples were digested with H_2SO_4 and digests were titrated by standard 0.01 M HCl for N concentration. Nitrogen uptake (N yield) of maize plant was calculated by multiplying the N concentration by the total aboveground dry weights. Nitrogen recovery was calculated by dividing the difference in maize N uptake in fertilized soil and unfertilized soil by the amount of total N added by urea and organic fertilizers, and expressed as percent. In fact, fertilize N recovery shows the N use efficiency (NUE) by maize as a function of urea and organic fertilizers.

N mineralization experiment

Net N mineralization (N_{min}) of fertilized and unfertilized soils was determined by an *in-situ* buried polyethylene bag technique in which surface soil samples were incubated through the growing season (Cusick et al., 2006). The soil was passed through a 2 mm sieve, thoroughly mixed with fertilizer treatments (UF, PM, CM and CM+UF) and placed in polyethylene bags. Three bags were randomly buried (30 cm depth) in the center of rows in each plot. The soil moisture content was maintained at 60% of field capacity. The N mineralization of fertilized and unfertilized soils was measured at 10 days intervals for a total of 110 days after fertilizer application. Soil mineral N was measured in an extract obtained by shaking a 5 g soil sample with 30 mL of 1 M KCl (1:6 soil to solution) in a rotary shaker for 60 min at 25 ^{o}C. The extracts were filtered with a Whatman's No. 42 filter paper. The extracts were analyzed for NO_3^--N and NH_4^+-N concentrations colorimetrically and then expressed as mg N kg^{-1} soil (Alef and Nannipier, 1995). All soil data were converted into kg ha^{-1} taking into account soil bulk density. The net N ammonification (kg ha^{-1}) was regarded as the net changes in NH_4^+-N concentration relative to its initial value during field incubation. The net nitrification (kg ha^{-1}) was defined as the difference in NO_3^--N before and after the field incubation. The net N mineralization (N_{min}, kg ha^{-1}) was calculated as the difference between total inorganic N (NH_4^+-N and NO_3^--N) before and after the incubation. Soil water content was also determined after drying subsamples at 105 °C for 24 h. Indeed, fertilizer total N_{min} (N mineralized) is the sum of the inorganic forms of the N in each treatment adjusted for N mineralization in the control (unfertilized) soil.

Statistical analysis

The results were examined by ANOVA and the Fisher's Protected least significant difference (LSD) test ($P \leq 0.05$) using software package SAS (SAS Institute, 2001).

Results and Discussion

Soil and manure characteristics

The soil characteristics measured at the beginning of the study are presented in Table 1. The concentrations of soil organic C, total N and available P were 0.48%, 0.06% and 11 mg kg^{-1}, respectively. The study soil initially contained 1.85 kg N ha^{-1} in plant-available form, mainly as NH_4^+-N (65%). There were differences in total N, total P, organic C and C/N ratios between PM and CM (Table 2). Poultry manure contained greater amounts of total N, total P and organic C than CM. The C/N ratio of PM (12.2) was lower than that of CM (20.5). Both manures had higher EC values (Table 2), showing the possibility for an accumulation of soluble salts following their applications.

N dynamics and fertilizer applications

The cumulative N mineralization (N_{min}) for unamended (control) soil is shown in Figure 1. Soil mineral N contents tended to increase rapidly as the field incubation proceeded. Results show that the total N mineralized from soil organic N was about 22 kg N ha^{-1} during the course of study (Figure 1), corresponding to a small proportion of soil total N (0.98%). This would mean a lower N availability for maize production in the study soil. We observed some variation in the cumulative N mineralization in unfertilized soil that could be due to changes in environmental conditions during the field incubation. More specifically, an increase in soil temperature from 28 ^{o}C in May to 38 ^{o}C in June-July could explain enhanced N mineralization measured at day 60 (Figure 1). The patterns of the cumulative net N mineralization (N_{min}) for all fertilizer treatments are shown in Figure 2. The net N mineralization (the sum of NO_3^--N and NH_4^+-N in fertilized soil minus the sum of NO_3^--N and NH_4^+-N in unfertilized soil) was significantly different among the sampling time and treatments. Overall, net N mineralization was higher in organic and urea fertilizers than the control soil at all sampling dates (Figures 1 and 2), showing no microbial N immobilization into soil biomass, presumably due to lower manure C/N ratios (< 21). This would further reveal that organic manures are potentially easily mineralized and that N immobilization is not likely to occur during the initial periods of crop growing season. Manure C/N ratio and N contents are usually the most important characteristics that influence N mineralization-immobilization of different organic fertilizers (Van Kessel and Reeves, 2002). However, the magnitude of net N mineralized/transformed from the fertilizers varied, depending on the type of fertilizer and incubation time. There was a rapid increase in the net N mineralization expressed as kg ha^{-1} in all fertilizers up to 30 days after the initiation of the experiment (Figure 2). More N was mineralized in CM + UF treatment compared with other treatments at 20 days, and there was no difference in N mineralization among UF, PM and CM treatments during the initial period of incubation (i.e., up to 20 days). Net N mineralization was greater for PM than other fertilizers, especially from day 30 onwards. Among fertilizers, total N mineralized over the entire experiment ranged from 109 kg N ha^{-1} in CM to 244 kg N ha^{-1} in PM (Table 3). These values are lower than those reported by Serna and Pomares (1991) and Sbih et al. (2003). Soils treated with PM showed greater (77%) total N mineralized than soil amended with UF. Similarly, Canali et al. (2004) reported that potential N mineralization was higher in PM amended soils than in urea-fertilized soils over a 6-year field experiment.

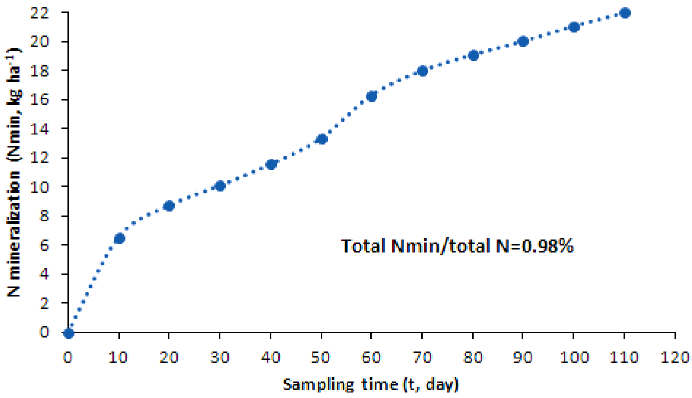

Figure 1. The pattern of cumulative net N mineralization (kg N ha^{-1} soil) from unamended soil during 110 day field incubation. Each point represents mean (n=4).

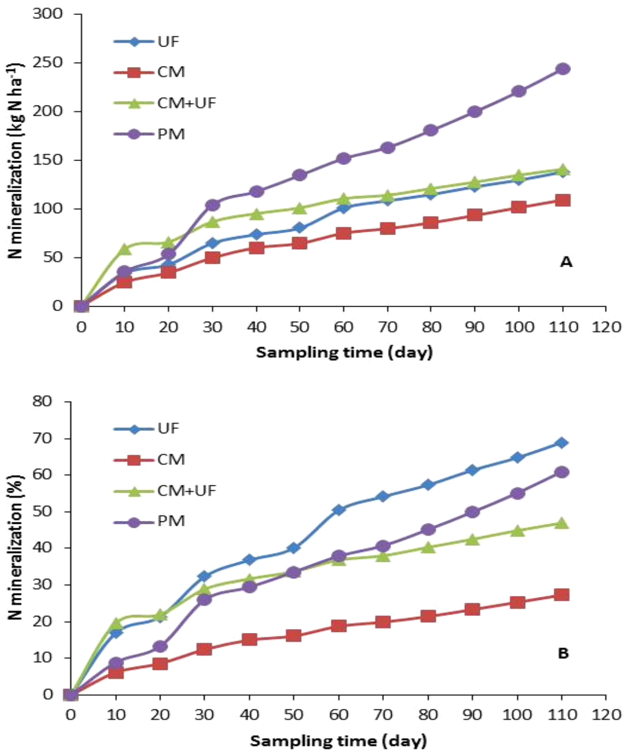

Figure 2. The patterns of cumulative net N mineralization from soils amended with organic and urea fertilizers, expressed as kg N ha^{-1} (A) and percentage of the added N (B) during 110 day field incubation under maize crop. Each point represents mean (n=4). UF=Urea, CM=Cow manure, CM+UF= Cow manure + Urea, PM=Poultry manure.

Table 3. The cumulative net NH_4, NO_3 and inorganic N (kg N ha^{-1} soil and %) released in fertilizer treatments during field incubation (110 days) under maize crop (n=4).

Fertilizer	NO_3^-	NH_4^+	N_{min} [a]	NO_3^-/N_{min}	NH_4^+/N_{min}	N_{min}
	(kg ha^{-1})			(%)		
Urea	55.1^b	82.8	138^b	40.8^b	59.2^a	69.0^a
Cow manure	43.6^b	65.5	109^b	40.0^b	60.0^a	27.8^c
Cow manure +Urea	41.2^b	99.7	141^b	30.8^b	69.2^a	47.0^b
Poultry manure	168^a	75.5	244^a	69.1^a	30.9^b	61.0^{ab}
P	<0.001	>0.05	<0.001	<0.001	<0.001	<0.001

[a] N_{min}: total net N mineralized (i.e., minus control soil).
Within each column, different letters indicate that fertilizer means are significantly different at P<0.05.

Expressed as a percentage of the organic and inorganic N added to the soil initially, total N mineralization varied from 28 to 69% of the initial N at 110 days at the end of the growing season (Figure 2, Table 3). Indeed, this expression shows fertilizer potential N availability, since it is based on a similar rate of total N added by fertilizers. The highest percentage of net N mineralization was observed in UF (69%) and PM (61%) treatments and the least in CM + UF (47%) and CM (28%) fertilizers. These values are within the range of those reported by previous studies (Chae and Tabatabai, 1986; Lupwayi and Haque, 1999; Qafoku et al., 2001; Eghball et al., 2002; Yadvinder-Singh et al., 2009). Eneji et al. (2002) observed that the rate of net N mineralization was highest in urea-treated soils and was very low in manure-treated soils, and that addition of UF stimulated soil N mineralization. However, the rate of UF hydrolysis found in this study (69%) over 110 days is much lower than that reported by other studies. Agehara and Warncke (2005) showed that over 90% of urea-N was hydrolyzed during 12 weeks of laboratory incubation. Lupwayi and Haque (1999) reported that about 28% of total N in cattle manure was mineralized over 105 days. Nitrogen mineralization in beef cattle feedlot manure was about 21% of organic N during the first growing season in conventional and no-till corn (*Zea mays* L.) systems under field conditions (Eghball, 2000). Qafoku et al. (2001) estimated that net N mineralization for different poultry manures ranged from 24 to 74% (on average 51%) during 112 days of incubation. Similar values (42-64%) were reported by Preusch et al. (2002) after 120 days of incubation. Yadvinder-Singh et al. (2009) observed that approximately 46% of poultry manure N was mineralized after 60 days of incubation, which is similar to the average value (48%) reported by Ruiz-Diazand Sawyer (2008). Probably, the higher organic N availability of PM (61%) than that of CM (28%) might be related to the quality of organic materials applied to the soil, in particular N content and C/N ratio (Table 2). It is possible that cow manure contained a large proportion of recalcitrant N compounds, which were resistant to the microbial decomposition (Chae and Tabatabae, 1986; Cordovil et al., 2005; Cordovil et al., 2007). On the contrary, organic N added with poultry manure may have more labile and easily mineralizable organic N compounds (Nahm, 2003; Nahm, 2005). Other studies reported that the higher N mineralization and availability with poultry manure might be due to the high active N fraction (21-67%) (Chae and Tabatabae, 1986; Cordovil et al., 2005; Cordovil et al., 2007). In addition, the availability of manure N was varied due to difference in organic matter content (Table 2) and degree of composition, or factors that affected microbial activity (Cordovil et al., 2007). Therefore, it is proposed that the amount of manure N mineralization can be a useful measure for estimating the N-supplying capacities or potential N availability of organic fertilizers under specific environmental conditions. This is very important especially in arid and semi-arid areas, where soils are poor in plant-available N and organic matter. Our data demonstrated that combining CM with urea-N resulted in an additional N release of about 19% from CM, but did not increase net N mineralization over the PM. This could be due to the proportional supply of both C and N for soil microorganisms. Additional C without sufficient N (as in CM alone) or additional N without sufficient C (as in UF alone) may lead to N limitation or C limitation, respectively, for soil microbes (Zhang et al., 2008). In other words, the addition of C resources in concomitant with mineral N to the surface soil may result in greater N and C availability for active soil microorganisms, with a consequence for the stimulation of sustainable microbial activity.

N forms and fertilizer applications

The application of urea and organic fertilizers resulted in a significant increase (65.5-99.7 kg ha^{-1}) in the cumulative net ammonification over the unamended soil (13.5 kg ha^{-1}) in this arid soil (Table 3). Although the increased net ammonification did not differ among fertilizers, CM in combination with UF treatment showed a greater net ammonification (99.7 kg ha^{-1}) than UF alone (82.8 kg ha^{-1}) followed by PM (75 kg ha^{-1}) and CM alone (65.5 kg ha^{-1}) during the field incubation (Table 3). This suggests that the addition of UF to CM stimulates NH_4^+-N production. Higher N availability of UF could have stimulated microbial activity (Raiesi, 2004), and subsequently more organic N from CM was mineralized and converted to NH_4^+-N. As with ammonification, the cumulative net nitrification increased in all fertilizer treatments (41-168 kg ha^{-1}) over the unfertilized soil (8.6 kg ha^{-1}) during the experiment (Table 3). The effect was significantly higher in PM fertilizer (168 kg ha^{-1}) than other fertilizers, followed by UF (55 kg ha^{-1}), CM (44 kg ha^{-1}) and CM + UF (41 kg ha^{-1}) treatments with no significant difference in the latters (Table 3). Results show that the main form of N mineralized was NO_3^--N for PM with a relative nitrification of 69% and a relative ammonification of 31% (Table 3); probably NH_4^+-N is oxidized and is converted rapidly into NO_3^--N in soils amended with this organic manure.

In other words, nitrifying bacteria reduced the NH_4^+-N concentrations of PM by converting NH_4 to NO_3. However, ammonium (NH_4) was the dominant form of mineral N during the entire period of experiment in soils amended with UF (59%), CM (60) and CM+UF (69%) (Table 3), indicating that the nitrifying microorganisms did not oxidize the available NH_4 entirely. It also indicates that the growth and activity of nitrifying bacteria was probably limited by higher NH_4 production from the urea-N and lower N availability from the CM. The effect of cow manure C should be unimportant, since the nitrifiers are autotrophic microbes and not dependent on the organic carbon added by the manures. At the end of the experiment, the lowest total N converted into NH_4^+-N was recorded in the soils amended with PM (31%) and was significantly lower than that observed with other fertilizers (59-69%), whereas the highest total N nitrified was seen in PM treatment (69%) that was significantly greater than that found in other treatments (31-41%, Table 3). The high rates of N mineralized and the predominance of net nitrification with PM during the whole period of experiment (Table 3) suggest that manure N availability occurs mainly as NO_3^--N. Our results also indicate that nitrification became the dominant N mineralization process in poultry manure-amended arid soils when a longer period (110 days) is considered, while ammonification was the dominant process in soils receiving UF and CM.

Maize dry weight and N uptake and recovery

The N concentrations in maize tissue were significantly higher in the fertilized soils (0.90-1.44%) than unfertilized soils (0.84%); showing greater mineral N available to maize in urea and manure-amended soils (Table 4). The increase in N concentration was 80% for UF, 11% for CM, 41% for CM + UF and 64% for PM. This suggests that the positive response to urea and manure N would be related to the low N availability of the study soil (1%, Figure 1). The higher N concentration in urea-treated maize than in other manure-treated maize indicates that urea-N was clearly more readily available to maize crop than other N resources.

Table 4. The effects of urea and organic fertilizers on maize N concentration, aboveground dry weights, N uptake, N recovery, and N uptake : total net N mineralization ratio under field conditions (n=4).

Fertilizer	N concentration	Dry weight	N uptake[a]	N Recovery[b]	N uptake: N_{min}
	(%)	(kg ha^{-1})	(kg N ha^{-1})	(%)	
Urea	1.44^{a}	12950^{b}	186^{b}	60.3^{a}	0.88
Cow manure	0.90^{c}	14087^{b}	126^{c}	15.3^{c}	0.56
Cow manure +Urea	1.18^{b}	14937^{b}	176^{b}	37.0^{b}	0.85
Poultry manure	1.24^{b}	18987^{a}	234^{a}	42.3^{b}	0.73
P	<0.001	<0.001	<0.001	<0.001	>0.05

[a] N concentration multiplied by total dry weights.

[b] N uptake in fertilizer treatment-control soil (unfertilized) divided by the amount of fertilizer N applied.

N_{min}: total net N mineralized.

Within each column, different letters indicate that fertilizer means are significantly different at P<0.05.

There were significantly higher maize dry weights in organic and urea treatments (70-150%) over the control soil (7600 kg ha^{-1}), indicating the positive influence of organic manures and UF fertilizer on the maize performance in these arid soils. It further indicates that the excess salinity found in both manures (7-13 dS m^{-1}, Table 2) was not a constraint for maize growth. The amendment of PM increased aboveground dry weights of maize plant more than UF and CM alone or in combination (Table 4). This would mean maize plant grew better in PM soil than in cow manure-and urea-amended soils. Though, there was no statistical difference in dry weights among CM, UF and CM+UF treatments, maize dry weight was slightly higher in CM+UF (14900 kg ha^{-1}) than in CM (14000 kg ha^{-1}) and UF (12900 kg ha^{-1}) treatments. In a field experiment, Mundus et al. (2008) observed that mixing cattle manure with *Gliricidiasepium*, a green manure to increase the quality and N concentration of cattle manure, increased maize productivity under semiarid conditions in Brazil.

Our results show that maize N uptake with PM soil (234 kg ha^{-1}) was considerably higher than those with UF (186 kg ha^{-1}) and CM + UF (176 kg ha^{-1}) soils followed by CM (126 kg ha^{-1}) soil. We found that a higher N uptake by maize crop is associated with a greater N mineralization in all the treatments (Figure 3). Cordovil et al. (2007) concluded that that poultry manure was the most efficient fertilizer among others to supply mineral N to wheat and ryegrass due to a greater N availability. The total cumulative N mineralization was well correlated to maize N uptake using a polynomial function, especially when N mineralization expressed as kg ha^{-1} (R^2=0.978, $P<0.05$, Figure 3). Similarly, Cordovil et al. (2007) reported that potentially mineralizable N from six organic wastes was correlated to plant N uptake by ryegrass and wheat. In another study, Irshad et al. (2002) showed that maize N uptake was higher in urea and cattle manure + urea treatments as compared to cattle manure in an infertile loamy sand soil. Abbasi and Tahir (2012) found that the combined application of urea and farmyard manure treatments had comparable wheat yields to UF treatment. In a study by Nyamangara et al. (2003) the combined use of cattle manure with N fertilizer increased N uptake by maize during all seasons compared with the sole manure. They hypothesized that the application of N fertilizers may overcome the negative impacts resulting from the application of low N cattle manure. Nonetheless, CM + UF treatment did not increase the uptake of N by maize compared with UF only treatment. The increased maize growth and N uptake following PM might also be due to improvements in soil structure, organic matter levels, cation exchange capacity, water holding capacity and microbial biomass (Haynes and Naidu, 1998; Manna et al., 2007).

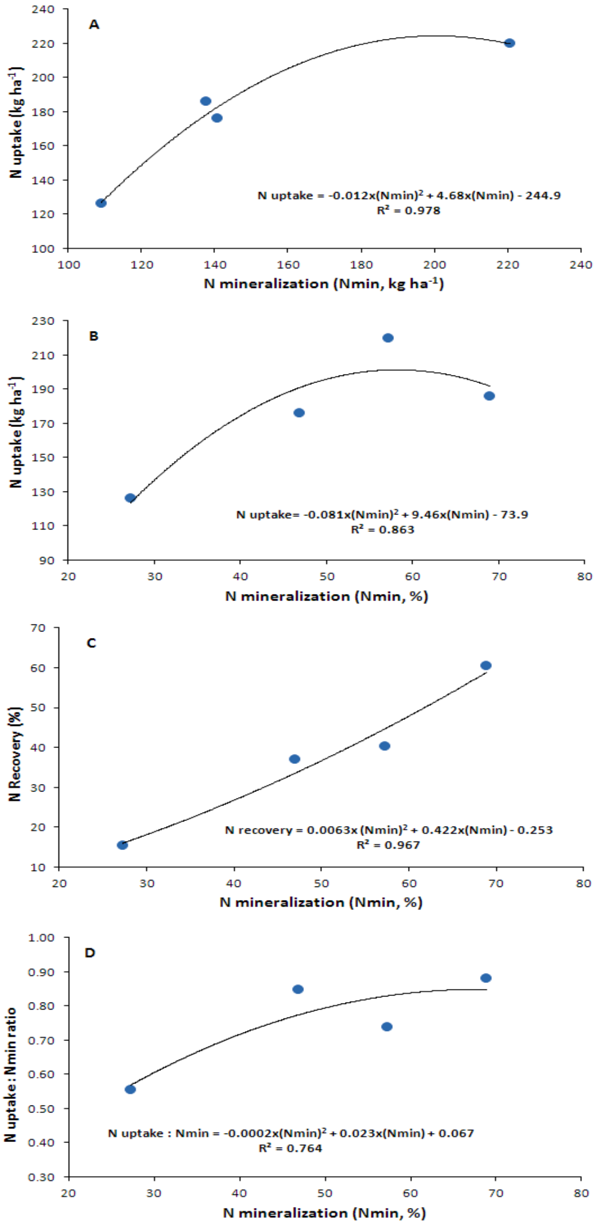

Figure 3. Quadratic regressions between mean total N mineralized (kg ha^{-1}) from fertilizers and maize N uptake (A), total N mineralized (%) and maize N uptake (B), total N mineralized (%) and maize N recovery (C) and total N mineralized (%) and N uptake: total N mineralization ratio (D) (n=4).

Fertilizer N recovery was calculated as the difference between N uptake in fertilized and unfertilized maize crops per unit of applied N to account for the difference in the amount of applied total N. Nitrogen recovery (as% of applied fertilizer N) by maize was 60% for UF, 42% for PM, 37% for CM + UF and 15% for CM fertilizers (Table 4). The lowest value observed with CM is associated with lower N availability of 28%, while the highest value with UF is due to greater N availability of 69% (Table 3). This is further confirmed by the significant polynomial relationship between fertilizer N recovery and N availability (R^2=0.967, P<0.01, Figure 3). The values of N recovery by maize crop correspond to the range of 21-56% reported by Yadvinder-Singh et al. (2004). Paul and Beauchamp (1993) found that the N recovery by corn (grain+stover) was 49 and 18% of the total N in urea and dairy cattle manure, respectively. In addition, data on N recovery suggests that organic N from CM is less mineralizable and that the application of CM with urea-N could increase maize N recovery by 22% (Table 4) that can be explained by higher N availability (Table 3). Similarly, Nyamangara et al. (2003) found that the recovery of N by maize increased significantly by combining cattle manure with mineral N over cattle manure alone. However, the application of cattle manyure+urea did not increase maize N recovery over the use of urea alone. Our results further indicate that maize N recovery in urea-amended soils is greater than that in poultry manure-amended soils, reflecting possible N losses through volatilization following PM application in these calcareous soils with relatively high pH (> 7.0). This difference in N recovery could be due to the split-application of urea-N into three equal applications during the growing season. On the other hand, with the application of PM, growing maize takes up mineralized N before it can be lost, probably due to the slow release of mineral N from this manure (Figure 2). This is further supported by the lower N availability in PM soils (61%) compared to the higher N availability in urea-treated soils (69%). However, N recovery is related to fertilizer type and the level of applied N fertilizer (Paul and Beauchamp, 1996).

We also calculated maize N uptake as a percentage of total N mineralized for amended soils (Table 4), and found no significant effect of fertilizer treatments on this value. A higher value for UF (88%) and a lower value for CM (56%) suggest that more available N from UF was recovered by the silage maize, and less available N recovered from CM (Table 4). We found a positive correlation between the ratio of N uptake from fertilizer to total N mineralization from fertilizer and manure, and N availability (P<0.05 and R^2=0.764, Figure 3).

Summary and Conclusions

The results of this study demonstrate that the total N mineralization was greater in PM than in CM and UF fertilizers, and that NO_3^--N was the dominant form of mineral N in soils amended with PM. N availability of UF fertilizer and PM was similar, but higher than that of CM. Maize aboveground dry weights and N uptake were considerably greater in PM soil than in UF and CM soils. However, maize N recovery was higher in UF fertilizer than in PM followed by CM. We found evidence that combining urea-N with CM to increase N contents of the later enhances organic N availability of CM, with subsequent increased N uptake and recovery by maize crop during the growing season. Furthermore, results of this experiment indicated that the application of PM alone or the combined application of CM+UF could be the most efficient fertilizers for improvement of maize production and N uptake due to a great potential for N mineralization and availability. In summary, these results suggest that the application of PM (11 Mg ha^{-1}) and CM (21.7 Mg ha^{-1}) in combination with urea-N (217 kg ha^{-1}) improves maize growth and production, with subsequent enhanced N uptake in arid soils with low SOM, soil moisture and N availability. Therefore, soil and manure N availability should be taken into account when applying UF or manure fertilizers in maize cropping systems as to successfully apply these N resources and lower the consequences for the environment.

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References

Abbasi, M.K., Tahir, M.M., 2012. Economizing nitrogen fertilizer in wheat through combinations with organic manures in Kashmir, Pakistan. Agron. J. 104, 169-177.

Adeli, A., Sistani, K.R., Rowe, D.E., Tewolde, H., 2005. Effects of broiler litter on soybean production and soil nitrogen and phosphorus concentrations. Agron. J. 97, 314-321.

Agehara, S., Warncke, D.D., 2005. Soil moisture and temperature effects on nitrogen release from organic nitrogen sources. Soil. Sci. Soc. Am. J. 69, 1844-1855.

Akiyama, H., Mctaggart, I.P., Ball, B.C., Scott, A., 2004. N_2O, NO, and NH_3 emissions from soil after the application of organic fertilizers, urea and water. Water Air Soil Pollut. 156, 113-129.

Akoumianakis, K.A., Karapanos, I.C., Giakoumaki, M., Alexopoulos, A.A., Passam, H.C., 2011. Nitrogen, season and cultivar affect radish growth, yield, sponginess and hollowness. Inter. J. Plant Prod. 5 (2), 111-120.

Alef, K., Nannipier, A., 1995. Methods in applied soil microbiology and biochemistry. Academic Press. London.

Araji, A., Abdob, Z.O., Joycec, P., 2001. Efficient use of animal manure on cropland-economic analysis. Bioresour. Technol. 79, 179-191.

Arslan, H., Guleryuz, G., Kirmizi, S., Gucer, S., 2005. Nitrogen mineralization in mine waste-contaminated soils. Fresenius Environ. Bull. 14, 900-906.

Azeez, J.O., Averbeke, W.V., 2010. Nitrogen mineralization potential of three animal manures applied on a sandy clay loam soil. Bioresour. Technol. 101, 5645-5651.

Azeez, J.O., Van Averbeke, W., Okorogbona, A.O.M., 2009. Differential responses in yield of pumpkin (*Cucurbita maxima* L.) and nightshade (*Solanumretroflexum* Dun.) to the application of three animal manures. Bioresour. Technol. 101, 2499-2505.

Barzegar, A.R., Yousefi, A., Daryashenas, A., 2002. The effect of addition of different amounts and types of organic materials on soil physical properties and yield of wheat. Plant Soil, 247, 295-301.

Bastida, F., Moreno, J.L., Hernandez, T., Garcıa, C., 2006. Microbiological degradation index of soils in a semiarid climate. Soil. Biol. Biochem. 38, 3463-3473.

Canali, S., Trinchera, A., Intrigliolo, F., Pompili, L., Nisini, L., Mocali, S., Torrisi, B., 2004. Effect of long term addition of composts and poultry manure on soil quality of citrus orchards in Southern Italy. Biol. Fertil. Soils, 40, 206-210.

Carter, M.R., Gregorich, E.G., 2008. Soil sampling and methods of analysis. Canadian Society of Soil Science, CRC Press, Taylor & Francis Group, Boca Raton.

Chadwick, D.R., John, F., Pain, B.F., Chambers, B.J., Williams, J., 2000. Plant uptake of nitrogen from the organic nitrogen fraction of animal manures: a laboratory experiment. J. Agric. Sci. 134, 159-168.

Chae, Y.M., Tabatabai, M.A., 1986. Mineralization of nitrogen in soils amended with organic wastes. J. Environ. Qual. 15, 193-198.

Conant, R.T., Dalla-Betta, P., Klopatek, C.C., Klopatek, J.M., 2004. Controls on soil respiration in semiarid soils. Soil. Biol. Biochem. 36, 945-951.

Cordovil, C.M., Cabral, F., Coutinho, J., 2007. Potential mineralization of nitrogen from organic wastes to ryegrass and wheat crops. Bioresour. Technol. 98, 3265-3268.

Cordovil, C.M., Coutinho, J., Goss, M., Cabral, F., 2005. Potentially mineralizable nitrogen from organic materials applied to a sandy soil: fitting the one-pool exponential model. Soil. Use Manage. 21, 65-72.

Cusick, P.R., Powell, J.M., Kelling, K.A., Hensler, R.F., Munoz, G.R., 2006. Dairy manure N mineralization estimates from incubations and litterbags. Biol. Fertil. Soils 43, 145-152.

Eghball, B., 2000. Nitrogen mineralization from field-applied beef cattle feedlot manure or compost. Soil Sci. Soc. Am. J. 64, 2024-2030.

Eghball, B., Wienhold, B.J., Gilley, J.E., Eigenberg, R.A., 2002. Mineralization of manure nutrients. J. Soil Water Conserv. 57, 470-473.

Eneji, A.E., Honna, T., Yamamoto, S., Saito, T., Masuda, T., 2002. Nitrogen transformation in four Japanese soils following manure+urea amendment. Commun Soil Sci. Plant Anal. 33, 53-66.

Gilmour, J.T., Koehler, M.A., Cabrera, M.L., Szajdak, L., Moore, Jr P.A., 2004. Alum treatment of poultry litter: decomposition and nitrogen dynamics. J. Environ. Qual. 33, 402-405.

Haynes, R.J., Naidu, R., 1998. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. Nutr. Cycl. Agroecosyst. 51, 123-137.

Irshad, M., Yamamoto, S., Eneji, A.E., Endo, T., Honna, T., 2002. Urea and manure effect on growth and mineral contents of maize under saline conditions. J. Plant Nutr. 25, 189-200.

Judith, N., Chantigny, M., Dayegamiye, A., Laverdiere, M., 2009. Dairy cattle manure improves soil productivity in low residue rotation systems. J. Agron. 101, 207-214.

Li, X., Sarah, P., 2003. Arylsulfatase activity of soil microbial biomass along a Mediterranean-arid transect. Soil Biol. Biochem. 35, 925-934.

Lupwayi, N.Z., Haque, I., 1999. Leucaena hedgerow intercropping and cattle manure application in the Ethiopian highlands. I. Decomposition and nutrient release. Biol. Fertil. Soils, 28, 182-195.

Mahmood, T., Azam, F., Hussain, F., Malik, K.A., 1997. Carbon availability and microbial biomass in soil under an irrigated wheat-maize cropping system receiving different fertilizer treatments. Biol. Fertil. Soils, 25, 63-68.

Manna, M.C., Swarup, A., Wanjari, R.H., Mishra, B., Shahi, D.K., 2007. Long-term fertilization, manure and liming effects on soil organic matter and crop yields. Soil Tillage Res. 94, 397-409.

Min, D.H., Islam, K.R., Vough, L.R., Weil, R.R., 2003. Dairy manure effects on soil quality properties and carbon sequestration in alfalfa-orchardgrass systems. Commun. Soil Sci. Plant Anal. 34, 781-799.

Monaco, S., Sacco, D., Borda, T., Grignani, C., 2010. Field measurement of net nitrogen mineralization of manured soil cropped to maize. Biol. Fertil. Soils, 46, 179-184.

Mundas, S., Menezes, R.S.C., Neergaard, A., Garrido, M.S., 2008. Maize growth and soil nitrogen availability after fertilization with cattle manure and/or gliricidia in semi-arid NE Brazil. Nutr. Cycl. Agroecosyst. 82, 61-73.

Nahm, K.H., 2003. Evaluation of the nitrogen content in poultry manure. World Poultry Sci. J. 59, 77-88.

Nahm, K.H., 2005. Factors influencing nitrogen mineralization during poultry litter composting and calculations for available nitrogen. World Poultry Sci. J. 61, 238-255.

Nyamangara, J., Piha, M.I., Giller, K.E., 2003. Effect of combined cattle manure and mineral nitrogen on maize N uptake and grain yield. Afr. Crop. Sci. J. 11, 289-300.

Paul, J.W., Beauchamp, E.G., 1993. Nitrogen availability for corn in soils amended with urea, cattle slurry, and solid and composted manures. Can. J. Soil Sci. 73, 253-266.

Paul, J.W., Beauchamp, E.G., 1996. Soil microbial biomass C, N mineralization and N uptake by corn in dairy cattle slurry-and urea-amended soils. Can. J. Soil Sci. 76, 469-472.

Preusch, P.L., Adler, P.R., Sikora, L.J., Tworkoski, T.J., 2002. Nitrogen and phosphorus availability in composted and uncomposted poultry litter. J. Environ. Qual. 31, 2051-2057.

Qafoku, O.S., Cabrera, M.L., Windham, W.R., Hill, N.S., 2001. Rapid methods to determine potentially mineralizeable nitrogen in broiler litter. J. Environ. Qual. 30, 217-221.

Raiesi, F., 2004. Soil properties and N application effects on microbial activities in two winter wheat cropping systems. Biol. Fertil. Soils, 40, 88-92.

Ruiz-Diaz, D.A., Sawyer, J.E., 2008. Plant-available nitrogen from poultry manure as affected by time of application. Agron. J. 100, 1318-1326.

Salazar, F.J., Chadwick, D., Pain, B.F., Hatch, D., Owen, E., 2005. Nitrogen budgets for three cropping systems fertilised with cattle manure. Bioresour. Technol. 96, 235-245.

SAS Institute, 2001. SAS user's guide: statistics, Version 8.2. Cary, NC.

Sbih, M., Dayegamiye, A., Karam, A., 2003. Evaluation of carbon and nitrogen mineralization rates in meadow soils from dairy farms under transit to biological cropping systems. Can. J. Soil Sci. 83, 25-33.

Serna, M.D., Pomares, F., 1991. Comparison of biological and chemical methods to predict nitrogen mineralization in animal wastes. Biol. Fertil. Soils, 12, 89-94.

Sistani K.R., Adeli, A., Mcgowen, S.L., Tewold, H., Brink, G.E., 2007. Laboratory and field evaluation of broiler litter nitrogen mineralization. Bioresour. Technol. 99, 2603-2611.

Tafte, A., Sepaskhah, A.R., 2012. Yield and nitrogen leaching in maize field under different nitrogen rates and partial root drying irrigation. Inter. J. Plant Prod. 6 (1), 93-114.

Van Kessel, J.S., Reeves III, J.B., 2002. Nitrogen mineralization potential of dairy manures and its relationship to composition. Biol. Fertil. Soils, 36, 118-123.

Van Kessel, J.S., Reeves III, J.B., Meisinger, J.J., 2000. Nitrogen and carbon mineralization of potential manure compounds. J. Environ. Qual. 29, 1669-1677.

Whitehead, D.C., Bristow, A.W., Pain, B.F., 1989. The influence of some cattle and pig slurries on the uptake of nitrogen by ryegrass in relation to fractionation of the slurry N. Plant Soil, 117, 111-120.

Williams, T.O., 1999. Factors influencing manure application by farmers in semi-arid west Africa. Nutr. Cycl. Agroecosyst. 55, 15-22.

Xing, G.X., Zhu, Z.L., 2000. An assessment of N loss from agricultural fields to the environment in China. Nutr. Cycl. Agroecosyst. 57, 67-73.

Yadvinder-Singh, Bijay-Singh, Ladha, J.K., Khind, C.S., Gupta, R.K., Meelu, O.P., Pasuquin, E., 2004. Long-term effects of organic inputs on yield and soil fertility in the rice-wheat rotation. Soil. Sci. Soc. Am. J. 69, 845-853.

Yadvinder-Singh, Gupta, R.K., Thind, H.S., Bijay-Singh, Varinderpal-Singh, Gurpreet-Singh, Jagmohan-Singh, Ladha J.K., 2009. Poultry litter as a nitrogen and phosphorous source for the rice-wheat cropping system. Biol. Fertil. Soils, 45, 701-710.

Yan, D., Wang, D., Yang, L., 2007. Long-term effect of chemical fertilizer, straw, and manure on labile organic matter fractions in a paddy soil. Biol. Fertil. Soils, 44, 93-101.

Zhang, N., Wan, S., Li, L., Bi, J., Zhao, M., Ma, K., 2008. Impacts of urea N addition on soil microbial community in a semi-arid temperate steppe in northern China. Plant Soil, 311, 19-28.