The Combined Influence of Broiler Litter and Mineral NP Fertilizers on Soil Chemical Properties, Maize Performance and Nutrient Uptake in a Calcareous Soil

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Abstract: Organic manures can be a valuable and inexpensive source of soil amending materials to supply plant nutrients, and to improve soil properties that are important for crop performance. However, effects of broiler litter on soil chemical properties and maize performance in arid and semi-arid areas are not well-known. The main objective of this study was to explore the interactive influence of broiler litter and chemical NP fertilizers on maize yield and chemical properties of a calcareous soil. The experiment consisted of two methods of fertilizer placements and seven fertilizer treatments conducted for two successive years under field conditions. Results showed that furrower method improved soil chemical properties and subsequently increased maize grain yield and dry matter production compared with disk + furrower method. The N and P levels in soil increased with the application of NP fertilizers and broiler litter. Soils amended with broiler litter and NP fertilizers had greater maize grain yield and dry matter production than the control. In conclusion, furrower placement combined with the application of broiler litter and 20% of the optimum chemical NP fertilizers were the most efficient nutrient management practice for increasing maize performance in the studied area.

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Introduction

Excessive use of mineral fertilizers as N and P sources contributes greatly to environmental contamination. The adverse effect of N and P over-fertilization on environmental quality is more significant in conventional agricultural systems (Sistani *et al.* 2004), where imbalanced fertilization is practiced over a long period. On the other hand, mineral fertilizers are neither available nor affordable, particularly in the developing countries. However, without the application of N and P fertilizers to crops, particularly in semi-arid soils, N and P deficiencies can rapidly occur (Ghosh *et al.* 2004). Consequently, fertilizer practices which result in good nutritional balance for crop production are highly desirable to make the most efficient and profitable use of nutrients applied, and to reduce environmental hazards attributed to the continued over-use of N and P fertilizers (Sadras 2002). Integrated plant nutrient management in crop nutrition can be considered as a superior and alternative fertilizer practice. The integrated nutrient management involves the use of inorganic and organic nutrients via organic inputs such as animal manures, sewage sludge, compost, crop residues and by-products with high organic C, N and P mineralizable in a short-term. Such practices could supply nutrients for crops, and hinder concurrently serious environmental problems associated with excessive applications of N and P fertilizes.

Nevertheless, it has been realized from long-term fertilizer experiments that neither chemical fertilizers nor organic manures alone can achieve sustainability in crop production (Prasad 1996), whereas the integrated use of organics and inorganic fertilizers can sustain a highly intensive production system. Previous studies have indicated that chemical fertilizer application is most effective when combined with organic inputs (Ghosh *et al.* 2004).

The application of organic amendments has long been known to preserve and improve soil quality and health besides providing several nutrients including N and P (Eghball 2002) for plant uptake. These materials are valuable resources as a fertilizer and soil conditioner in crop production, particularly in arid and semi-arid soils with low organic C and N contents (Raiesi 2007). Furthermore, organic amendments are important sources of organic matter that can be returned to soil for nutrient recycling, and to improve soil physical, chemical and biological properties that are equally important for the maintenance of soil productivity and fertility (Liu *et al.* 2007; Kowaljow and Mazzarino 2007). Amongst various organic amendments, broiler litter is an alternative organic amendment for improving soil properties and for enhancing crop growth in most agricultural production systems (Adeli *et al.* 2005). This manure is a relatively inexpensive source of macronutrients (i.e. N, P, K, Ca, Mg, and S) and micronutrients (i.e. Cu, Zn, Fe, Mn, and B). It has been indicated that broiler litter increases soil organic C and stimulates soil microbial activities (Liu *et al.* 2007), which contribute to plant growth via increasing the cycling of soil nutrients.

The application of these materials to soils was a traditional source of nutrients and organic matter for soil-plant systems and has received considerable attention in recent years. However, there are various opinions on the benefits of broiler litter concerning its long-term effect on the levels and availability of soil nutrients and other soil chemical properties (Edwards *et al.* 1992). It has been demonstrated that broiler litter contributes to plant growth through the favorable effects on soil physical, chemical and biological properties (Ghosh *et al.* 2004). However, the continued use of broiler litter may increase the potential for NO3-N enrichment in groundwater and P eutrofication in surface waters (Edwards *et al.* 1992). Yet Jokela (1992) indicated that poultry manure application resulted in soil profile NO3-N concentrations similar to or slightly less than those found with agronomically equivalent rates of chemical N fertilizers. Eghball (2002) reported evidence of plant-available P leaching following four years of manure application on a silty clay loam surface soil. Short and long term application of poultry litter increased Cu and Zn concentrations in soil, specially in the top 5 to 10-cm (Han *et al.* 2000).

Nitrogen and P nutrition play a critical role in maize (*Zea mays* L.) production, especially in calcareous soils with low organic matter contents (Moss *et al.* 2001). More importantly, the supply of N and P in maize cropping could sustainability improve plant growth and yields, particularly in semi-arid regions (Damodar Reddy *et al.* 2000). Although most of N and P required by maize can be provided through the chemical fertilizers, addition of these nutrients via broiler litter may enhance maize yield (Moss *et al.* 2001) and this may further improve soil chemical fertility (Edwards *et al.* 1992). It has been reported that broiler litter enhanced grain yields of maize, soybean and cotton, due most probably to increased plant nutrient availability and improved soil structure (Gascho *et al.* 2001; Adeli *et al.* 2005). However, very little is known about the effects of this manure on soil chemical fertility and maize performance when combined with nitrogen and fertilizers in Iran. Due to support by the government, poultry farming system in Iran is increasing, and subsequently litter application in agricultural crop production received a considerable interest in recent years. Thus, the objective of this study was to explore the interactive influence of broiler litter and chemical NP fertilizers on maize yield and chemical properties of a calcareous soil from Iran.

Materials and Methods

A field experiment was conducted on a silty clay soil (fine, non-montmorillonitic, thermic, type Chromudert) at the Agricultural Research Farm of Lorestan Weather Department, Khorram-Abad, Iran (33º 23'N, 48º 36'E, 1620 m above sea level) for two consecutive years (2004-2005). The climate of area is semi-arid with a mean annual precipitation of 620 mm, most of the rain falling between October and January, and a mean annual air temperature of 14.3 ºC with a maximum of 39 ^{o}C in summer and a minimum of -2 ^{o}C in winter. Initially, soil samples from 0 to 30 cm depth of the field were collected, dried and ground to pass a 2-mm sieve. The soil ECe value was measured using saturated paste methods as outlined by Janzen (1993). Soil pH was determined in a 1:2 (w/v) soil/water suspension using a pH meter with a glass electrode. The total N concentration was measured by the Kjeldahl method (Bremner and Mulvaney 1982), and available P and K were extracted by the Mehlich-1 method (Donohue *et al.* 1983). Phosphorus was determined colorimetrically and K by atomic absorption spectroscopy (Donohue *et al.* 1983). Soil organic matter content was determined only in samples from the 0 to 30 cm depth by the combustion and titration method. All concentrations were expressed on an oven-dried weight basis. The initial soil properties prior to the experiment are presented in Table 1. Broiler litter was obtained from a Poultry Farm Station nearby the experimental site. The manure was analyzed for some chemical properties as described above, and on the average had the following properties on a dry weight basis: EC, 9.5 dS m^{-1}; pH, 5.8; O.C, 404 g kg^{-1}, total N, 41.7 g kg^{-1}; P, 10.8 g kg^{-1} and K, 18 g kg^{-1}.

The experiment was arranged in a split-plots layout based on randomized complete block design with four replications. The main plots consisted of two methods of fertilizer placements, which are common practices throughout the studied area: 1) furrower (F) method including tillage + furrower, and 2) disk + furrower (DF) method including tillage + disk + furrower. The fertilizer treatments (subplots) included in the current study were:

T0: without chemical fertilizer and broiler litter (as control); T1: 200 kg N ha^{-1} and 100 kg P ha^{-1} (recommended optimum rates of urea and super phosphate triple, respectively); T2: 80% of T1+ 4 Mg ha^{-1} of broiler litter (as integrated treatment); T3: 60% of T1+ 8 Mg ha^{-1} of broiler litter (as integrated treatment); T4: 40% of T1+ 12 Mg $ha^{-1}$of broiler litter (as integrated treatment); T5: 20% of T1+ 16 Mg ha^{-1} of broiler litter (as integrated treatment); T6: 20 Mg ha^{-1} of broiler litter (as organic treatment).

Table 1. Some characteristics of the experimental site at 0–30 cm soil depth and broiler litter in the study.

Properties	Soil	Broiler litter		
		2004	2005	Average
Texture	Silty clay	-	-	-
Bulk density (Mg m^{-3})	1.31	-	-	-
pH (1:2.5, soil: water)	7.39	5.6	6.0	5.8
EC (dS m^{-1})	0.63	8.8	10.2	9.5
Total soil organic C (g kg^{-1})	10.7	424	385	404
Total N (g kg^{-1})	1. 07	42.4	41.0	41.7
Available P (mg kg^{-1})	4.2	12400	9200	10800
Available K (mg kg^{-1})	400	21400	14700	18000

Application of 20 Mg ha^{-1} of broiler litter provided 834 kg N ha^{-1} and 216 kg P ha^{-1}. Maize (KSC 704) was seeded at 40 kg ha^{-1} and sown in May, 2004 and 2005. The size of each plot was 3m × 7m and consisted of six rows with a distance of 75 cm and a distance of 20 cm between plants on each row. Thirty three percent of N and all of P fertilizers were applied before seed preparation and the remaining N was added 42 days after sowing. Potassium fertilizer was not applied to the soil due to the initial soil K level of 400 mg kg^{-1} (Table 1), which adequately provides maize growth with available K. The desired broiler litter rates were surface-applied each year before sowing the maize, and immediately incorporated into the soil surface by either furrower (F) or disk + furrower (DF). Furrow irrigation, which is also common in the studied region, was applied at the flow rate of 1.4 $l\ s^{-1}$ at weekly intervals. In the second year, similar treatments were applied to the same plots. The harvest operations were done on 14 Sep. 2004 and 19 Sep. 2005. Maize grain yield was estimated at maturity stage by hand-harvesting the four middle rows at each plot. Grain yield is reported at grain moisture content of 140 g kg^{-1}. Grain samples were dried in a forced-air oven at 60°C, ground to pass a 0.5-mm sieve, and analyzed for total N by combustion method (Campbell 1992) and for P and K using inductively coupled argon plasma emission spectroscopy (ICP) on a dry-ashed sample (Donohue and Aho 1992). From the grain yield and N, P, and K concentration, nutrient uptake by grain was calculated. Finally, soil samples were taken to 30 cm depth for the determination of soil ECe, pH, soil organic matter, and available N, P and K concentrations at harvest in both years. Six soil cores (8 cm diameter and 7 cm height) were taken randomly from each of the three center rows of each plot at 30 cm depth. This resulted in six soil sub-samples per plot. Then, all sub-samples from a single plot were pooled, placed in plastic bags, and frozen at -4ºC until analyzed. The chemical properties of soil samples were measured by the same methods described for the initial soil samples.

The statistical analysis was performed using PROC ANOVA in SAS (Version 8.02 SAS Institute 2001). The original data were checked for equal variance and normal distribution before analysis. Data were analyzed as a spilt plot by ANOVA. Since the effect of year on dependent variables was significant, data for each year were analyzed separately. Treatment means were separated using the Least Significant Difference (LSD) test. Differences were considered significant only when P values were lower than 0.05, unless expressed otherwise. Regression between soil chemical parameters and maize performance was fitted to linear and polynomial functions, and the regression equation with highest correlation coefficient between data was selected.

Results and Discussion

1. Treatment effects on soil properties

1.1 Soil ECe, pH and organic matter

Our data indicated no significant differences in soil ECe values and OM contents at 0-30 cm depth between furrower and disk + furrower methods in both 2004 and 2005 (Table 2). However, soil pH was significantly lower ($P<0.05$) with furrower than with disk + furrower method only in the first year of experiment.

Across the years, application of broiler litter or mineral fertilizers resulted in higher soil ECe values than the T0 (control) and T1 (100% NP) treatments (Table 2) except in 2005. Soil ECe in 60% NP + 8 Mg broiler litter treatment (T3) was significantly higher than that in T0, T1 and T2 treatments in the second year of experiment. The highest soil ECe values were recorded for 40% NP +12 Mg broiler litter treatment (T4) in both years (2.60 and 2.72 dSm^{-1} respectively for 2004 and 2005, Table 2). The increase in ECe could be explained as the addition of chemical fertilizers to soil increases the amount of soluble salts and the release of some nutrients during decomposition of broiler litter could have contributed to higher soil ECe. Addition of broiler litter alone (T6) decreased significantly soil ECe values relative to T4 treatments. Additionally, the initial litter ECe was high (9.5 dSm^{-1}), and this could also have contributed to the increased soil ECe in litter-amended plots. Kowaljow and Mazzarino (2007) also reported that soil electrical conductivity in all amended and fertilized plots was significantly higher than in the control. Broiler litter application decreased soil pH in both years (Table 2) but the decrease was not statistically significant, due probably to very high buffering capacity of calcareous soils, and most likely the short duration of the current experiment. These results are similar to the findings of Chang *et al.* (1991) who reported a 0.3 to 0.7 units decline in pH of calcareous soils (pH 7.8) in the top 15 cm following eleven years of cattle manure application. The small decreases in soil pH could be attributed to the nitrification of NH_4 as well as the various organic acids produced during the decomposition of the labile fraction of the manure. In contrast, increased soil pH has been obtained from broiler litter in other studies (Han *et al.* 2000). There was a placement method × fertilizer NP treatment interaction (P<0.01) for soil ECe in both years (Fig.1). With furrower method, soil ECe values in T0, T1 and T2 treatments were much higher than those in other treatments in the first year of study, whereas T1 and T2 treatments showed greater soil ECe values than those in other treatments in 2005.

Table 2. Soil chemical properties after maize harvest as affected by the combined use of broiler litter and mineral NP fertilizers.

Treatments	EC ($dS\ m^{-1}$)		pH		OM ($mg\ kg^{-1}$)		N ($mg\ kg^{-1}$)		P ($mg\ kg^{-1}$)		K ($mg\ kg^{-1}$)	
	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Placement method												
Furrower	2.02	2.20	7.61	7.65	19.9	20.2	1.15	1.16	6.95	14.5	342	345
Disk+ Furrower	2.16	2.42	7.69	7.66	19.4	20.2	1.13	1.17	10.5	16.8	359	331
LSD[b]	NS[c]	NS	**	NS	NS	NS	NS	NS	*	NS	NS	*
Nutrient treatment												
Control	1.32	1.30	7.72	7.70	18.1	18.2	1.05	1.05	3.7	4.2	333	310
T1	1.96	1.28	7.66	7.74	19.4	19.2	1.12	1.11	9.0	7.6	329	349
T2	1.98	1.25	7.68	7.76	19.2	19.7	1.11	1.14	10.4	17.7	331	320
T3	2.25	2.54	7.67	7.68	20.0	19.7	1.12	1.14	10.3	13.1	331	337
T4	2.60	2.72	7.58	7.64	19.2	20.8	1.18	1.21	12.5	17.3	368	363
T5	2.34	2.64	7.62	7.53	20.5	21.5	1.19	1.25	11.8	17.7	375	383
T6	2.17	2.44	7.63	7.57	21.0	22.1	1.22	1.28	9.2	22.6	385	404
LSD (p< 0.05)	0.53	0.51	0.06	0.15	1.4	0.66	0.07	0.04	2.9	3.13	36.2	32.4
Interaction	**	**	NS	NS	*	NS	NS	NS	NS	NS	NS	NS

* p≤ 0.05, ** p≤ 0.01.

[a] F: furrower method including tillage + furrower; DF: Disk + Furrower method including tillage + disk + furrower; control: without chemical fertilizer and broiler litter; T1: 200 and 100 kg ha^{-1} of N and P, respectively; T2: 80% of T1+ 4 Mg ha^{-1} of broiler litter; T3: 60% of T1+ 8 Mg ha^{-1} of broiler litter; T4: 40% of T1+ 12 Mg ha^{-1} of broiler litter; T5: 20% of T1+ 16 Mg ha^{-1} of broiler litter; T6: 20 Mg ha^{-1} of broiler litter.

[b]LSD: least significant difference.

[c]NS: non-significant.

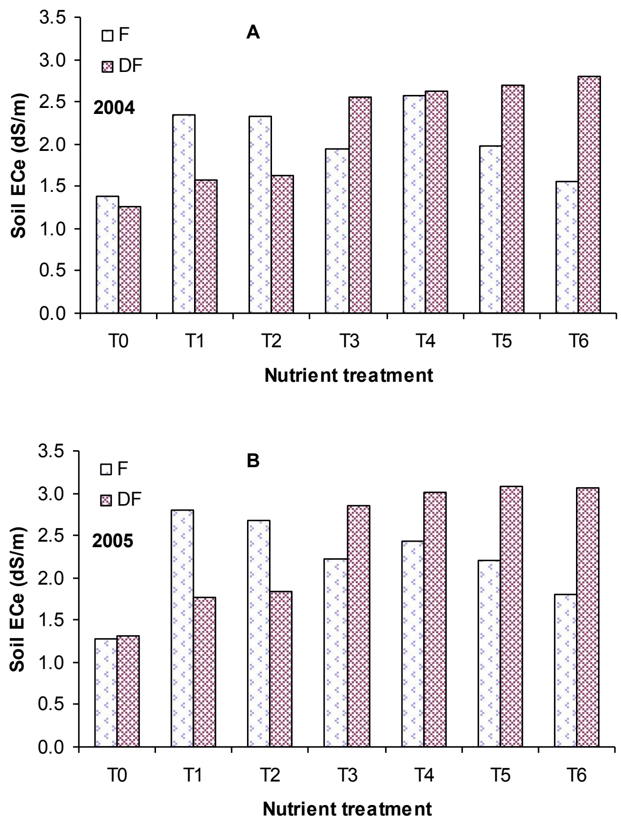

Figure 1. Interaction of fertilizer placement method and nutrient treatment for soil ECe in 2004 (A) and 2005 (B). F: Furrower method including tillage + furrower; DF: Disk + furrower method including tillage + disk + furrower; T0: without chemical fertilizer and broiler litter; T1: 200 and 100 kg ha-1 of nitrogen and P, respectively; T2: 80% of T1+ 4 Mg ha-1 of broiler litter; T3: 60% of T1+ 8 Mg ha-1 of broiler litter; T4: 40% of T1+ 12 Mg ha-1of broiler litter; T5: 20% of T1+ 16 Mg ha-1 of broiler litter; T6: 20 Mg ha-1 of broiler litter.

Similarly, OM contents were affected by fertilizer treatments (Table 2). Soil organic matter content was significantly greater in most integrated use of chemical NP and organic fertilizers than those in the control, particularly in 2005. Our data indicated significantly greater OM levels in T4, T5 and T6 treatments than in other treatments. Increasing rate of litter application led to increased OM contents in the soil. Addition of organic manure through broiler litter could most likely explain the increase in organic carbon concentrations in the integrated treatments (Benbi *et al.* 1998). The relationship between the total N added and soil OM contents was described using a second order polynomial function, rather than a linear function (Fig.2). This 2nd-order polynomial function explained approximately 80% of the soil OM variability in 2004, and 89% of OM variability in 2005. Other reported data display that organic manures were most effective in increasing soil OM, especially its labile fractions, and next was chemical fertilizers or manure plus chemical fertilizers (Yan *et al.* 2007). Therefore, application of NP fertilizers in conjunction with organic manure is needed to enhance soil OM in these calcareous soils, specifically characterized by low levels of organic matter (Raiesi 2004). Soil organic matter is a key attribute of soil fertility because of its impact on soil chemical, physical, and biological properties and processes in soils. However, OM is not sensitive to short-term changes of fertility with different fertilizer practices due to high background levels and natural soil variability (Haynes 2005). Significant interactions ($P<0.05$) were observed between placement method and fertilizer NP treatment for soil OM in 2004 (Fig. 3). With furrower method, soil organic matter contents in T2 and T4 treatments were much greater than those in other treatments.

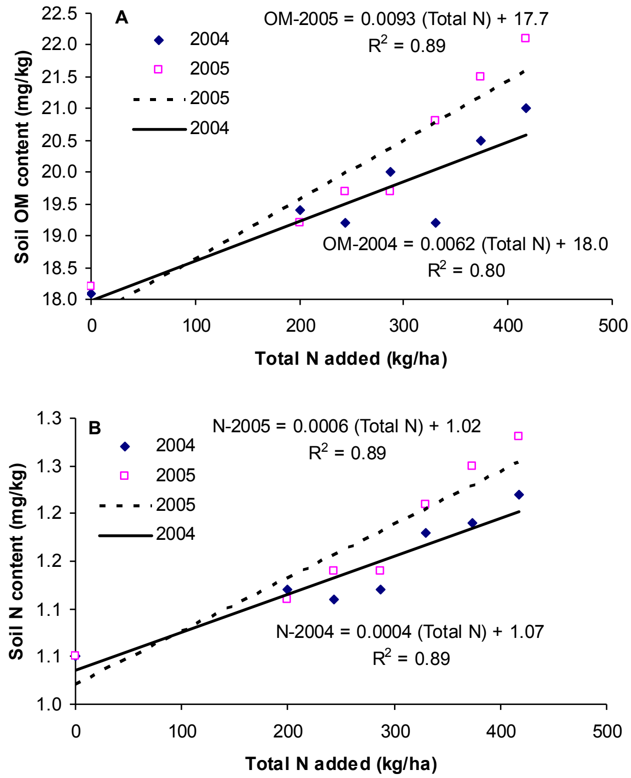

Figure 2. Relationship between total N added from chemical fertilizers and broiler litter, and soil organic matter (OM) contents (A) and soil N contents (B) for both 2004 and 2005. The curves show the linear regression fitted to the data.

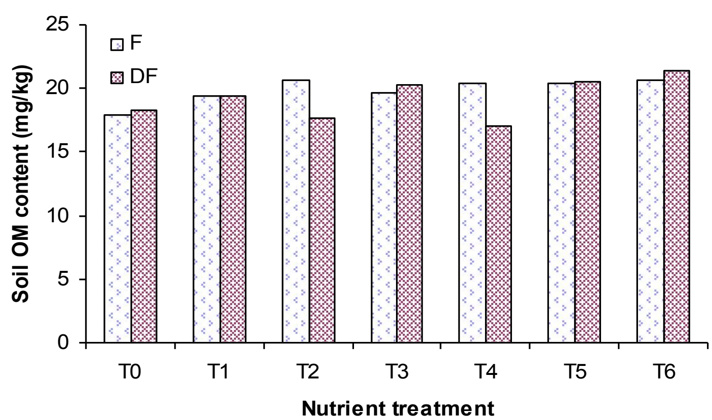

Figure 3. Interaction of fertilizer placement method and nutrient treatment for soil organic matter (OM) in 2004. See Figure 1 for abbreviations

1.2 Soil nutrients (NPK)

Soil total N quantities were not different between furrower and disk+ furrower methods, indicating that the total N is not affected by methods of fertilize placement (Table 2). However, soil P contents were different between furrower and disk + furrower methods only in 2004. The furrower method showed significantly lower ($P<0.05$) soil P content than the disk + furrower method. It seems that that the furrower method might supply enough P for crop growth, and that the potential for P residual effect would be minimal in the following years. In 2005, soil P was not affected by the method of fertilizer placement. On the other hand, P is an immobile element and is relatively accumulated in surface soil, and therefore its poor uptake by roots may occur for the succeeding crop.

The low density of plant roots and soil surface drought that are common in arid and semi-arid areas may further decrease P uptake. These results are in agreement with the findings of Fallah *et al.* (2006) who also observed significant decreases in soil P concentration in the furrower method. In contrast, levels of soil K was significantly higher in furrower method than disk + furrower method. Total N and P concentrations in the 0-30 cm soil increased slightly from 2004 to 2005 (Table 2), due most likely to addition of P and litter fertilizers in the second year of experiment. However, K concentration decreased from 2004 to 2005. This could be explained by greater K uptake remaining in the soil from the first year. The initial soil K level could adequately provide maize growth with available K, hence this nutrient was not applied to the soil. Negative K balance in the mineral fertilizer treatments of the rainfed cotton was indicated by Blaise *et al.* (2005).

Fertilizer treatments had significant effects on soil nutrient concentrations. In general, treatments received either broiler litter alone (T6) or in combination with mineral NP fertilizers had greater N, P and K contents than the T0 and T1 treatments in both years (Table 3). Soil total N increased with increasing litter rate for any fertilizer treatment. This might be ascribed to higher organic matter content in the plots where NP fertilizers were applied alone or in conjunction with broiler litter. The increase in soil N was more remarkable in 2005 than in 2004. In the first year, T4, T5 and T6 had greater soil N than T0 to T3 treatment, whereas all NP and litter-fertilized plots (T1 to T6) had higher soil N levels than the control (T0) treatment in the second year. This indicates the residual effects of broiler litter on soil N. Across the 2 years, residual soil total N levels at the 0-30 cm depth increased from 121 mg kg^{-1} with T4 treatment to as much as 128 mg kg^{-1} with T6 treatment, suggesting a lower N recovery at this rate of broiler litter. Similarly, Blaise *et al.* (2005) observed a positive nutrient balance when both mineral fertilizers and manures were applied in combination at the field experiment for lasted 3 years. While this amount of residual N is not large for arid and semi-arid soils with water scarcity, excess N is a potential risk for the environment (Adeoye and Agboola 1985). However, by exporting nutrients in the form of hay from lands receiving broiler litter, the rate of nutrient accumulation in the soil and the potential for ground and surface water pollution may be reduced (Sims and Wolf 1994).

Decreasing rates of NP fertilizers and increasing rates of broiler litter consistently increased soil P contents (Table 3). In both years, chemical NP fertilizers and litter application increased soil P levels compared with in the control (no NP fertilizer and litter added). Similar to that of N, soil P concentrations in 2004 were greater than those in 2005, especially with T6 treatment, indicating the residual effects of broiler litter on soil P, and probably less P recovery by maize in manure-amended plots. Organic manures, particularly broiler litter, are good sources of P (above 1 %) and therefore their applications may help P accumulation in soil profile (Omeira *et al.* 2006). Previous studies reported that 72% of broiler litter P retained in the soil profile (Sharpley *et al.* 1993).

2. Treatment effects on maize performance

2.1 Maize grain yield and dry matter production

Grain yield associated with furrower method was significantly greater than that associated with disk + furrower method by 1.23 Mg ha^{-1} in 2004 (Table 3). However, a reverse trend was observed in 2005 (10.8 vs. 10.4), although the effect was not statistically significant. Similarly, dry matter production in furrower methods was significantly greater than that in disk + furrower methods by 2.20 Mg ha^{-1} in 2004, and by 1.39 Mg ha^{-1} in 2005. This indicates that furrower method may favor maize dry matter and grain yields more than disk + furrower method.

There were no fertilizer placement method × nutrient treatment interactions for maize grain yield and dry matter production (Table 3), so only the main effects of fertilizer placement method and nutrient treatment are presented. Application of chemical fertilizers and broiler litter affected the grain yield of maize (Table 3). Plots fertilized with broiler litter and chemical nutrients produced significantly higher grain yield than did the plots fertilized with either mineral nutrients alone (T2) or no fertilizers (T0) in both years of study (Table 3). The average grain yield of maize over the two years in the T5 treatment (11.61 Mg ha^{-1}) was 15.4% and 39.2% higher than that in the 100%NP (T1) and control (T0) treatments, respectively. Beneficial effects of the combined use of organic and inorganic fertilizers in increasing the yield of various crops as well as maintaining soil health in the long-term had also been reported by other studies (Ghosh *et al.* 2004).

A significant positive relationship was found between soil N and P contents, and grain yields with the best fit being a polynomial function (Fig. 4 and 5). Such a positive relationship has been found for other crops. Therefore, differences in soil N and P contents (Table 2) resulted in by fertilizer treatments probably explain most of the variation (>80 %) in grain yield. Role of litter in increasing maize yield in the present study could be attributed to supply of all essential nutrients (Table 2) released during mineralization of broiler litter. In agreement with our results, increased yields have been obtained from broiler litter applications in cotton cropping systems (Gascho *et al.* 2001). On the other hand, the remarkable effect of broiler litter application on maize grain yield could be ascribed to its favorable effect on soil physical and biological properties (Sistani *et al.* 2008). Application of broiler litter has frequently been demonstrated to improve soil physical (Liu *et al.* 2007) and biological properties (Liu *et al.* 2007; Sistani *et al.* 2008).

Table 3. Maize grain yield, dry matter and nutrients uptake in grain as affected by the combined use of broiler litter and mineral NP fertilizers.

Treatments	Grain yield		Dry matter		N		P		K	
	(Mg ha^{-1})									
	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Placement method										
Furrower	10.5	10.8	21.6	22.7	174	177	40.8	61.5	29.6	54.5
Disk+ Furrower	9.24	10.42	19.36	21.3	167	166	35.5	56.0	28.1	59.7
LSD[b]	**	NS[c]	**	**	NS	NS	**	NS	NS	NS
Nutrient treatment										
Control	7.03	7.42	15.3	15.8	100	97.6	23.4	29.5	18.4	26.2
T1	9.91	10.2	19.9	21.1	179	166	37.0	47.9	32.5	45.7
T2	10.5	10.4	21.3	22.3	185	172	38.2	59.9	29.9	51.8
T3	9.72	10.7	21.4	21.4	176	168	44.5	66.8	31.2	55.2
T4	10.8	11.8	21.8	25.0	192	202	41.6	78.2	29.7	71.1
T5	11.0	12.3	23.3	24.9	192	202	42.6	70.8	30.0	80.0
T6	10.1	11.3	20.3	23.2	169	190	39.5	58.2	30.1	63.3
LSD ($p< 0.05$)	0.77	0.81	2.45	1.48	13.9	25.5	6.3	17.0	4.5	7.0
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* $p\leq 0.05$, ** $p\leq 0.01$.

[a] F: furrower method including tillage + furrower; DF: Disk + Furrower method including tillage + disk + furrower; control: without chemical fertilizer and broiler litter; T1: 200 and 100 kg ha^{-1} of N and P, respectively; T2: 80% of T1+ 4 Mg ha^{-1} of broiler litter; T3: 60% of T1+ 8 Mg ha^{-1} of broiler litter; T4: 40% of T1+ 12 Mg ha^{-1}of broiler litter; T5: 20% of T1+ 16 Mg ha^{-1} of broiler litter; T6: 20 Mg ha^{-1} of broiler litter.

[b]LSD: least significant difference.

[c]NS: non-significant.

According to Edwards *et al.* (1992) if poultry manure is added in combination with chemical fertilizers, it may supplement all nutrients to crop, and as a result may increase crop productivity. Our results also showed that the maize responded more to the combined use of broiler litter and mineral fertilizers than their sole application. This is because of the fact that approximately 74% of the total P and 50% of the total N in poultry manure are in plant-available form (Shepherd and Withers 1999) and maize being a heavy feeder of nutrients, particularly N, take up N faster from available pool of applied broiler litter.

Similar to that of grain yield, nutrient treatments affected significantly maize dry matter production (Table 3). Dry matters increased with increasing rate of litter and decreasing rate of chemical NP fertilizers. The greatest dry matter production in 20% of full NP + 16 Mg broiler litter per ha (T5) treatments corresponds well with the enhanced N concentrations in the same treatment (Table 2). Dry matter production was positively correlated with soil N and P concentrations (Fig. 4 and 5). A polynomial regression with R^2>0.89 provided a better description of the relationships between soil N and maize dry matters. This suggests that the increased soil N contents due to increasing amount of litter application rates was an important factor in affecting maize dry matter production. Various studies have shown large amounts of litter N mineralization, depending on the length of incubation periods. Most studies reported a mean value of 50-55 % for four months of incubation (Sistani *et al.* 2008). On the other hand, application of chemical fertilizers may stimulate most microbial activities such as C mineralization (Raiesi 2004) and N mineralization and microbial biomass (Yan *et al.* 2007). The enhanced microbial activities and biomass could help more nutrients become released from the native soil organic matter and the added litter for maize growth (Tejada *et al.* 2008). Soil biological processes positively influence the overall fertility of soil. However, soil fertility and crop yield production depend upon many factors, the most important being nutrient contents, and physical and chemical properties.

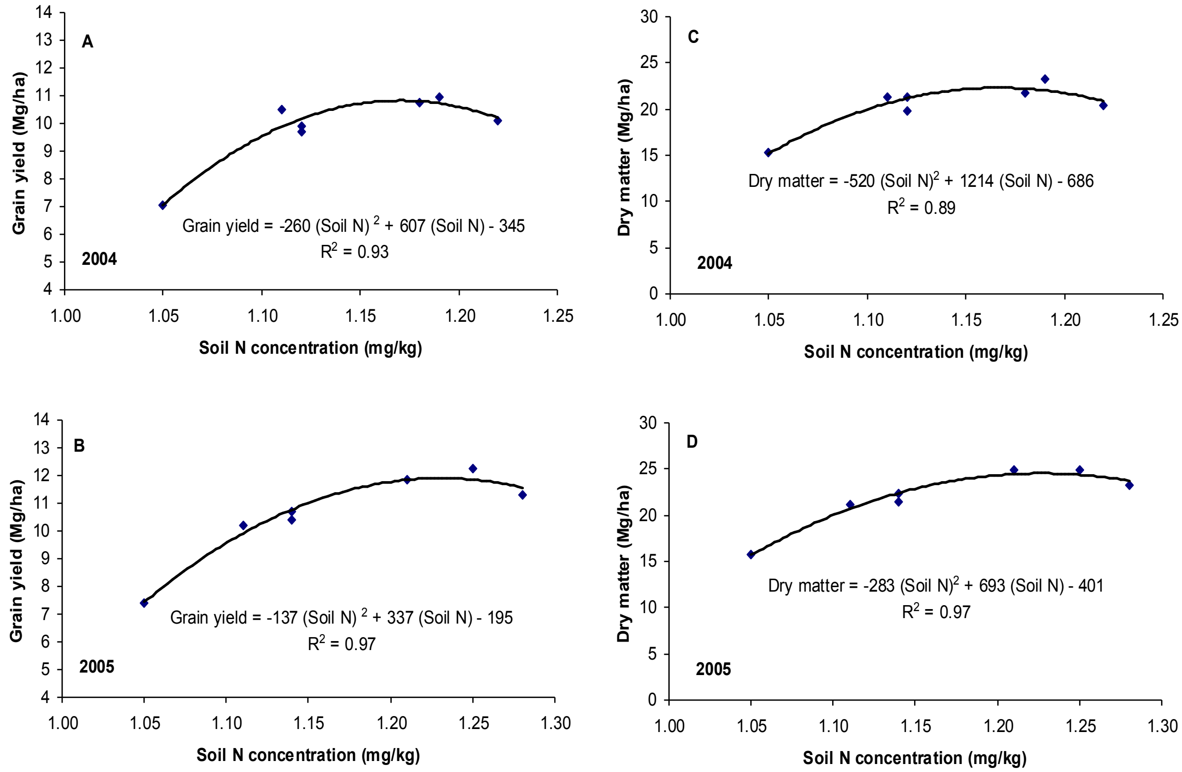

Figure 4. Relationship between soil N levels and maize performance, measured as grain yield (A and B, respectively for 2004 and 2005) and dry matter production (C and D, respectively for 2004 and 2005). The curves show the polynomial regression fitted to the data.

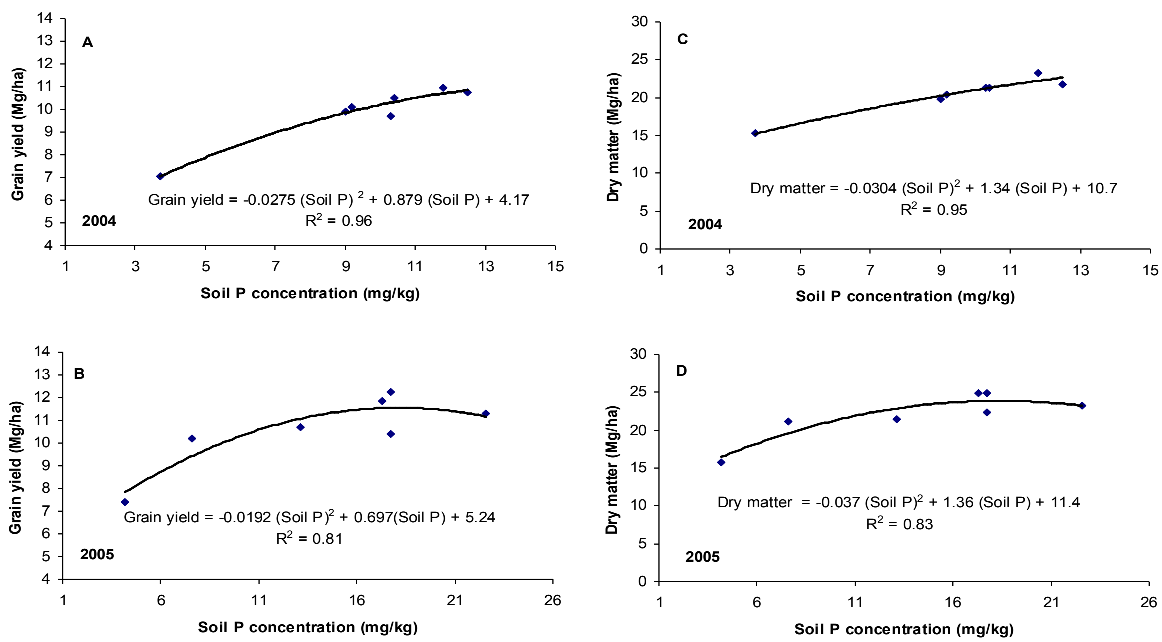

Figure 5. Relationship between soil P levels and maize performance, measured as grain yield (A and B, respectively for 2004 and 2005) and dry matter production (C and D respectively, for 2004 and 2005). The curves show the polynomial regression fitted to the data

2.2 Grain nutrient uptake

We calculated maize N, P and K uptake in grain using N, P and K concentrations multiplied by their yields. The concentration of nutrients in maize grain is determined by plant uptake, and depends on the level of available nutrients in the soil (Pederson *et al.* 2002). Generally, the method of fertilizer placement had no significant effects on N and K uptake in maize grain in both years (Table 3). The only significant effect of placement method was higher P uptake in furrower method in 2004.

Data indicated no fertilizer placement method × nutrient treatment interactions for nutrient uptake by maize. Thus, the main effects of treatments are reported (Table 3). Litter application and the integrated use of litter with NP fertilizers caused significant increases in N, P and K uptake (Table 3). The highest N uptake was found in T4 and T5 treatments in both years. Averaged across the two years, litter amended plots (T5) had the greatest N and K uptake (179 and 55 kg ha^{-1}, respectively). The maximum P uptake was observed in T3 treatment in 2004 and in T4 treatment in 2005 (Table 3). In 2004, there were few differences among treatments for K uptake. However, the larger differences were observed in 2005.

Apparent N and P recovery in grain was calculated by subtracting the amount of N and P taken up by maize in the control (without broiler litter and NP fertilizer) treatments from the N and P taken up by maize in each broiler litter and NP fertilizer treatments divided by the total N and P added from both fertilizers (Adeli *et al.* 2005; Mundus *et al.* 2008). Results show significant differences in apparent N and P recovery among the nutrient treatments (Fig. 6). Apparent N and P recovery decreased with decreasing inputs of chemical fertilizers and increasing inputs of broiler litter in both years. There was greater N recovery in T1 and T2 treatments than in other treatments. Similarly, Adeli *et al.* (2005) indicated that apparent N recovery by soybean decreased with increasing broiler litter and commercial fertilizer application rates. The results obtained in this study are in contrast with reports by Mundus *et al.* (2008) showing greater N recovery by maize received higher rates of *Gliricidia sepium* as green manure. Nitrogen recovery is a critical indicator of nutrient use efficiency and may reflect relative amounts of N remaining in or lost from the soil. Thus, lower N and P recovery in plots with high rates of broiler litter found in this study may indicate remarkable residual effect on the succeeding crops. Organic manures often leave residual effect on the succeeding crop in the system (Ghosh *et al.* 2004). Interestingly, the grain yield and dry matter of maize, and N and P uptake in treatment with higher rates of litter were consistently greater in 2005 than in 2004 (Table 3), indicating the residual effect of N and P applied in litter manure for succeeding year.

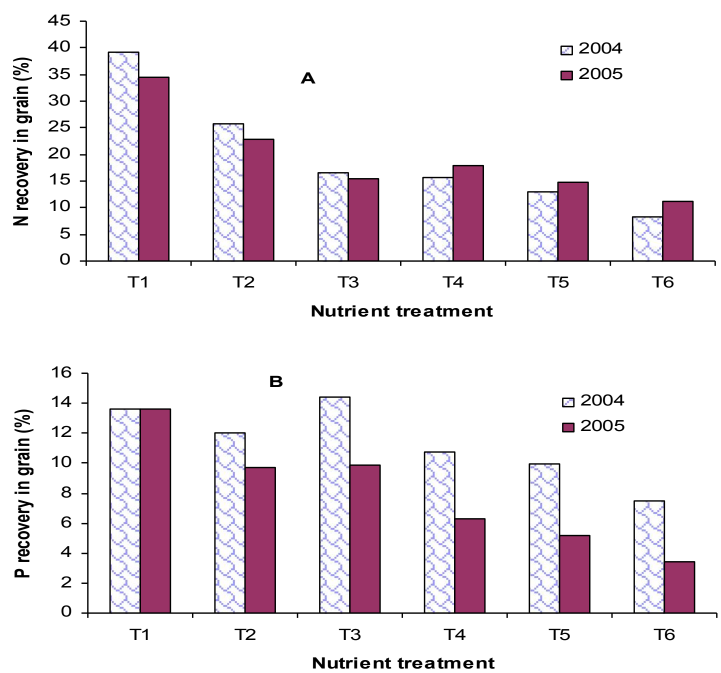

Figure 6. Apparent N (A) and P (B) recovery in maize grain as affected by different rates of chemical NP fertilizers and broiler litter. See Figure 1 for abbreviations.

Concluding remarks

In general, furrower method improved soil chemical properties and subsequently increased maize grain yield, dry matter production and P uptake by grains compared with disk + furrower method, particularly in the first year of experiment. Plots received broiler litter and NP fertilizers had greater maize grain yield and dry matter production than control plots without organic and inorganic fertilizers. The increases in the grain yield and dry matter of maize were much greater in 2005 than in 2004. Addition of 16 Mg ha^{-1} broiler litter in combination with 40 kg N ha^{-1} and 20 kg P ha^{-1} recorded higher grain yield and dry matter than other treatments. Furrower placement combined with the application of broiler litter and 20% of the optimum chemical NP fertilizers were the most efficient nutrient management practice for increasing maize performance in the studied area. In summary, balanced application of inorganic and organic fertilizers greatly influences maize performance in calcareous soils of the studied area.

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