Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/sjar

Spanish Journal of Agricultural Research 2007 5(1), 102-109
ISSN: 1695-971X

Effect of poultry litter on silage maize (*Zea mays* L.) production and nutrient uptake

J. Hirzel[1]*, I. Matus[1], F. Novoa[2] and I. Walter[3]

[1] *Instituto de Investigaciones Agropecuarias. Centro Regional de Investigación Quilamapu. Avda. Vicente Méndez, 515. Chillán. Chile*
[2] *Universidad de Concepción. Avda. Vicente Méndez, 595. Chillán .Chile*
[3] *Departamento de Medio Ambiente. INIA. Ctra. de A Coruña, km 7,2. 28080 Madrid. Spain*

Abstract

In Chile, the availability of poultry manure has recently increased as a result of expanding poultry production. The application of this organic waste on agricultural land is desirable since it not only helps recycle nutrients but also solves the problem of its disposal. A two year field study was undertaken to compare the effects of poultry litter (PL) and traditional mineral fertilizer on the growth of silage maize (*Zea mays* L.). The effects of adding mean annual PL rates of 10, 15 and 20 Mg ha^{-1}, with and without mineral fertilizer, were compared with those of two rates of conventional mineral fertilizer and a control treatment (no fertilizer). Crop yield showed a positive response to the fertilized treatments and fluctuated between 26.30 and 37.13 Mg ha^{-1}; values for the controls ranged between 17.12 and 23.80 Mg ha^{-1}. The yield averages obtained with the PL treatments were 13.85 and 9.05 Mg ha^{-1} higher than the controls in the first and second year respectively. Nutrient uptake was similar with the PL and conventional fertilizer treatments. The mean of apparent efficiency of N recovery (AENR) for the PL treatments was higher than that of conventional fertilizer treatments, suggesting PL to be an appropriate N supply that suffers only small N losses. The highest AENR was obtained with the lowest PL dose, indicating this to be the most appropriate rate. In conclusion, PL is an efficient alternative to conventional mineral fertilizers for silage maize production.

Additional key words: N efficiency recovery, nutritional needs, soil fertilizer.

Resumen

Efecto de la aplicación de cama de broiler sobre la producción y absorción de nutrientes en maíz para ensilaje (*Zea mays* L.)

La disponibilidad de estiércol o cama de broiler (CB) en Chile ha aumentado, como resultado del incremento en la producción de carne de ave. La utilización de este residuo orgánico en la actividad agrícola es beneficiosa, contribuyendo al reciclaje de nutrientes y disminuyendo su acumulación en zonas de producción. Para comparar el efecto de la aplicación de CB y fertilizantes convencionales sobre la producción de maíz para ensilaje, se realizó un experimento de campo durante dos años consecutivos. Se comparó el efecto de la aplicación de CB en dosis de 10, 15 y 20 Mg ha^{-1}, incluyendo en algunos casos la aplicación de nitrógeno, con la utilización de dos dosis de fertilizantes convencionales y un control sin fertilización. El rendimiento mostró una respuesta positiva a la fertilización, fluctuando entre 26,30 y 37,13 Mg ha^{-1}; en tanto que en el control fluctuó entre 17,12 y 23,80 Mg ha^{-1}. El rendimiento medio obtenido con la CB fue 13,85 y 9,05 Mg ha^{-1} mayor que el control sin fertilización para el primer y segundo año, respectivamente. La absorción de nutrientes fue similar entre los tratamientos con CB o fertilizantes convencionales. La eficiencia de recuperación aparente de N (AENR) media para los tratamientos con CB fue mayor que la obtenida con fertilización convencional, lo cual sugiere un suministro adecuado y bajo riesgo de pérdidas de N desde la CB. La mayor AENR se obtuvo con el uso de CB en baja dosis, resultando la más adecuada para este experimento. En conclusión, el uso de CB es una alternativa eficiente al uso de fertilizantes convencionales en el cultivo de maíz para ensilaje.

Palabras clave adicionales: eficiencia de recuperación de N, fertilización del suelo, necesidades nutricionales.

* Corresponding author: jhirzel@inia.cl
Received: 24-10-06; Accepted: 01-02-07.

Introduction

In Chile, 119,320 ha of silage maize (*Zea mays* L.) were cultivated in 2004 (INE, 2004a) — until then the largest area ever devoted to this crop. Silage maize is cultivated under irrigation between 29°20’ and 44°04’ S. It is commonly fertilized with conventional fertilizers (inorganic sources), but several authors have shown it to respond well to manures and composts (Parkinson *et al*., 1999; Adegbidi and Briggs, 2003; Ferguson *et al.,* 2005). Organic matter has successfully been used as a source of nutrients and organic matter for other crops, and significant benefits have been reported in terms of nutrient supply to both planted and successive crops (Muir, 2001; Sullivan *et al*., 2002; Barbarick and Ippolito, 2003; Cuevas *et al*., 2003; Daudén and Quílez, 2004). The main commercial manure produced in Chile is poultry litter (PL), i.e., poultry excreta mixed with bedding material. Over the last ten years there has been an increase in its production as poultry production has expanded. In 2004 the production of broiler chickens was 446,233 Mg (INE, 2004b), which generated an estimated 290,108 Mg of PL.

In agriculture, the main reasons for applying PL include the organic amendment of the soil and the provision of nutrients to crops (Evers, 2002; Singh *et al*., 2004; Warren *et al*., 2006). This is an effective way of recycling nutrients. Poultry wastes contain all the nutrients essential to plants, but improper management can contribute to the NO_3 and P pollution of water and the eutrophication of surface waters (Sims and Wolf, 1994). Thus, PL must be used in safe manner if the environment is not to be adversely affected (Sharpley, 1996).

Poultry waste application rates are usually based on the N requirements of the crop. Since N is often the most production-limiting nutrient, PL has typically been applied at rates that supply sufficient amounts of this nutrient.

Poultry waste is usually richer in N than other livestock wastes because birds have a common duct for the elimination of urine and faeces. Thus, estimating the availability of N from PL is important if appropriate application rates, i.e., that will benefit crops but pose no environmental risk, are to be used. Maize also has a high potassium demand and synergism exists between nitrogen and potassium fertilization. The positive yield response to PL is in part due to its high potassium content (Anon, 1997).

The aims of the present study were (i) to determine the dry matter production and nutrient uptake of silage maize receiving PL fertilization under field conditions over a two year period in the central region of Chile, and (ii) to assess N recovery by this crop from PL.

Material and Methods

Study site and experimental design

The present work was performed at the Santa Rosa experimental farm, *Centro Regional de Investigación* Quilamapu, Chillán – INIA, Chile (36°36’ S, 71°54’ W), between 2002 and 2004. The soil at the site, a Typic Melanoxerands (USDA, 1994), had a silty loam texture with an average depth of 0.6 m (Table 1). The climate of the area is Mediterranean with high temperatures and low rainfall during summer, and lower temperatures and high rainfall during winter (Fig. 1). The trial area had been cropped with spring wheat in previous years.

The experimental site was divided according to a fully randomised block design with four replicates per fertilizer treatment. Each of the six plots within a block measured 5 × 3.5 m, allowing 5 rows of maize drilled at 0.70 m spacing.

Table 2 shows that the treatments were a control non fertilized (T1), two rates of mineral fertilizer (T2 and T3), and three doses of PL (10, 15 and 20 Mg ha^{-1}; T4,

Table 1. Initial characteristics of the soil

Parameters	Depth (cm)	
	0 to 20	20 to 40
Bulk density (g cm^{-3})	1.20	1.25
Total porosity (%)	54.72	52.83
Water retention to 0.33 bars (%)	30.02	25.42
Water retention to 15 bars (%)	15.17	13.44
pH	6.5	6.5
OM (%)	6.1	6.4
N inorganic (mg kg^{-1})	15	14
P Olsen (mg kg^{-1})	11	11
K exchangeable ($cmol_c$ kg^{-1})	0.22	0.25
Ca exchangeable ($cmol_c$ kg^{-1})	5.81	5.31
Mg exchangeable ($cmol_c$ kg^{-1})	0.44	0.42
Na exchangeable ($cmol_c$ kg^{-1})	0.06	0.04
Al exchangeable ($cmol_c$ kg^{-1})	0.04	0.04
Fe available (mg kg^{-1})	33.70	33.51
Mn available (mg kg^{-1})	5.24	4.50
Zn available (mg kg^{-1})	0.43	0.41
Cu available (mg kg^{-1})	1.70	1.52
B available (mg kg^{-1})	0.31	0.46
S available (mg kg^{-1})	12.75	13.17

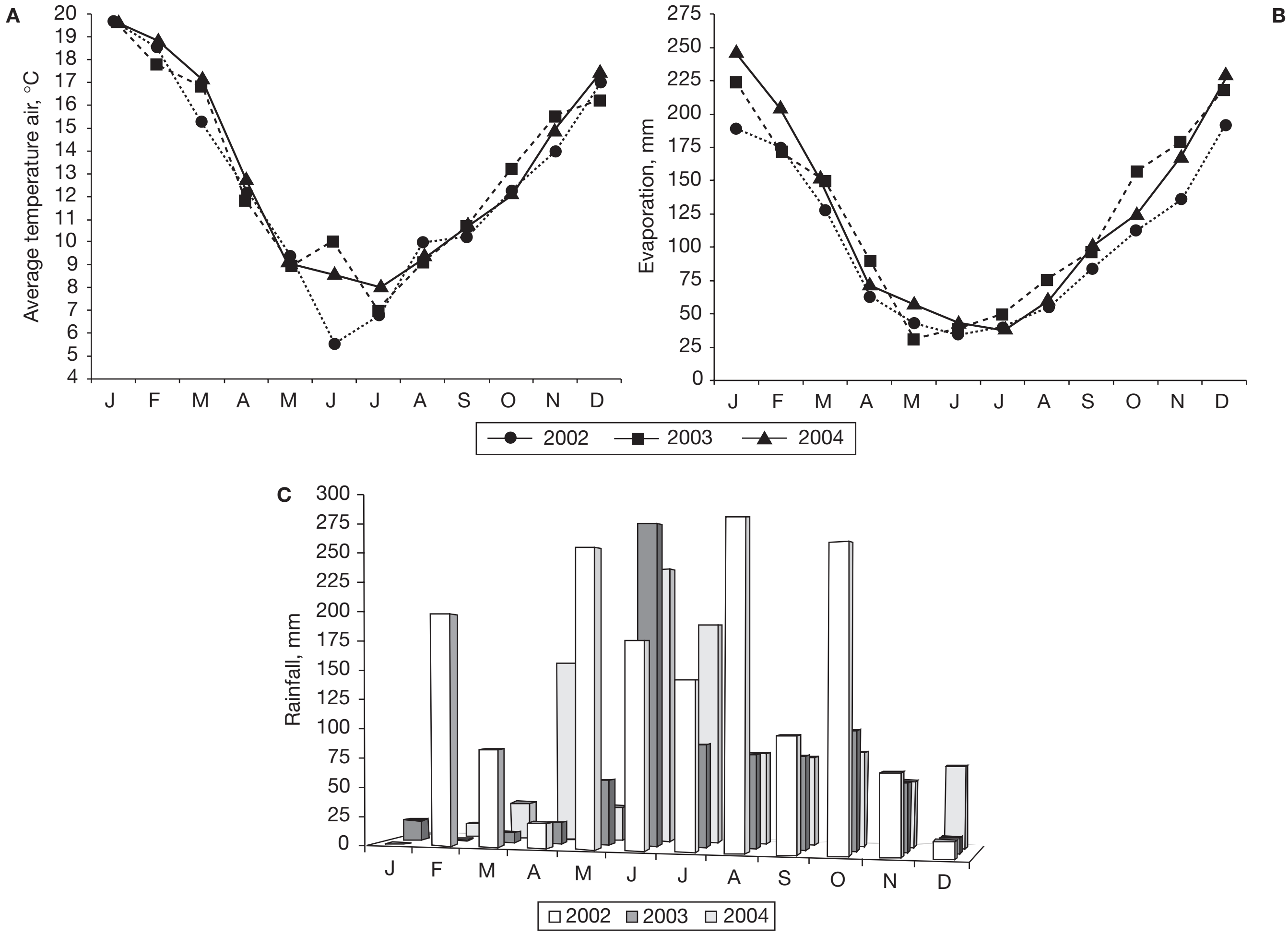

Figure 1. Climatic characteristics of the experimental site for the experimental period. A: Average temperature. B: Evaporation. C: Rainfall.

Table 2. Rates of N, P_2O_5 and K_2O used in the experiment

Treatment	Year	Sources		N	P_2O_5	K_2O
		Before sowing	After sowing	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})
T1	2002	—	—	0	0	0
	2003	—	—	0	0	0
T2	2002	Mineral	Mineral	300	156	147
	2003	Mineral	Mineral	300	156	147
T3	2002	Mineral	Mineral	400	234	220
	2003	Mineral	Mineral	400	312	294
T4	2002	PL	Mineral	300	156	147
	2003	PL	Mineral	300	156	147
T5	2002	PL	Mineral	400	234	220
	2003	PL	Mineral	400	312	294
T6	2002	PL	—	400	312	294
	2003	PL	—	400	312	294

T1: control. T2: low dose mineral fertilizer. T3: high dose mineral fertilizer. T4: low dose PL . T5: mid dose PL. T6: high dose PL. PL: poultry litter.

T5 and T6 respectively). Treatments T4 and T5 were accompanied by an application of 100 kg ha^{-1} of mineral N (urea) at the six leaf stage. The PL was hand-applied one day before sowing, while the conventional mineral fertilizer treatment was hand-applied as 50% one day before sowing and 50% at the six leaf stage. In addition, phosphorous (triple super phosphate) and potassium (potassium chloride) were applied one day before sowing. The same treatments were applied to each plot in each of the two years of the trial, moreover in the year 2003 T3 and T5 were accompanied by an application of 78 and 74 kg ha^{-1} of P_2O_5 and K_2O respectively. This made equal the P_2O_5 and K_2O rates applied with the PL in high rate, thus allowing any cumulative effects to be assessed.

The PL used in the study was collected from poultry houses in central Chile. Table 3 shows its average composition, as determined from the analysis of five samples collected over the experimental period.

Crop husbandry

All plots were cultivated to optimise crop growth according to standard agronomic practices for forage maize in the Central Region of Chile. The trial site was ploughed in winter each year. The PL and mineral fertilizer were then applied and the soil prepared to form an acceptable seedbed with the use of conventional tillage equipment. Seed was drilled with a disinfected standard drill. After emergence, weed control was performed with a combination of herbicides depending on the year and weed pressure observed. Over the two years the initial plant population was 102,041 plants ha^{-1}.

Table 3. Main component of the poultry litter used (dry weight adjusted)

	Mean	σ
Dry matter, g kg^{-1}	700	± 119
pH (1:2.5 PL-water)	8.05	± 1.1
EC, dS m^{-1}	7.36	
Organic C, g kg^{-1}	337	± 12.47
Total N, g kg^{-1}	28.57	± 8.0
N-NO_3, mg kg^{-1}	7,166	
N-NH_4, mg kg^{-1}	1,712	
Total P, g kg^{-1}	9.73	± 7.2
Total K, g kg^{-1}	16.79	± 12.5
Total Ca, g kg^{-1}	16.07	± 8.95
Total Mg, g kg^{-1}	4.79	± 1.6
Total S, g kg^{-1}	3.0	± 1.0
Zn, mg kg^{-1}	190	
Cu, mg kg^{-1}	180	

σ: standard deviation. EC: electrical conductivity.

In 2002 (first year) the crop was sown on November 10^{th} and harvested the following March 25^{th}. In the second year these dates activities were performed on October 16^{th} 2003 and February 25^{th} 2004 respectively. The cultivar used in the first years was DK-567 (Dekalb); in the second years P 3527 (Pioneer) was sown. The crop was harvested at the moment of silage maturity (i.e., when it represented 30-35% of the dry matter of the whole plant) (Plénet and Lemaire, 2000; Millner *et al*., 2005). In each plot, 10 contiguous plants from the central row were cut 10 cm above the soil surface and weighed. Harvested weights were recorded as fresh yields. The moisture content was determined by oven drying at 70ºC for 48 h.

Data collection and analysis

The silage yield and plant N, P, K, Ca and Mg concentrations for the six treatments were determined. Dried subsamples were ground with a mill to pass a 2 mm sieve and analysed. Total N was determined by the macro-Kjeldahl procedure, and total K, Ca and Mg by atomic emission (K) and atomic absorption (Ca and Mg) spectrophotometry following dry-ashing at 500°C and acid digestion (2M HCl). P was measured in the same extracts by colorimetry following the molybdate ascorbic acid method.

Nitrogen efficiency for the growing season (AENR) was calculated as the difference between the N total uptake of each fertilizer treatment and the control, divided by the total N applied (Rees and Castle, 2002):

$$AENR = [(N_{Ti} - N_{T1}) / Ndose_{Ti}]$$

where N_{Ti} = N uptake for treatment (kg ha^{-1}); N_{T1} = N uptake for control (kg ha^{-1}); $Ndose_{Ti}$ = N applied for treatment (kg ha^{-1}).

The results were examined by ANOVA and the least significant difference (LSD) test (P = 0.05) using the SAS general model procedure (SAS Institute, 1989).

Results

The dry matter production (Fig. 2) did no present significant differences between the mineral and organic

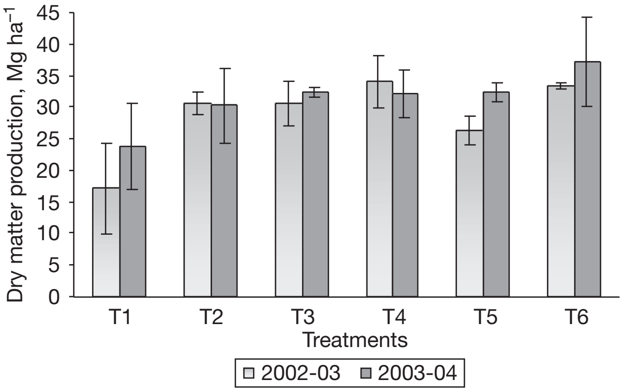

Figure 2. Silage maize dry matter yields for the two years of the experiment. The vertical bars are standard errors. T1: control. T2: low dose mineral fertilizer. T3: high dose mineral fertilizer. T4: low dose PL. T5: mid dose PL. T6: high dose PL.

fertilizer treatments in the first year, although in the second year significant differences were seen between T6 and T2 (Fig. 2). The production obtained in the first year fluctuated between 17.1 and 34.0 Mg ha^{-1} and between 23.8 and 37.1 Mg ha^{-1} for the second year. In the first year the average yields obtained with the PL treatments were approximately 2% and 44% higher than those obtained with the mineral fertilizer and the control treatment respectively. In the second year these differences were 8% and 30% respectively.

Table 4 shows the mean plant N content, N uptake and AENR for each treatment in both years of the study. N uptake by the crop was not affected by the mineral fertilizer rates applied in either year of the study. However, in the first year the N uptake differed significantly depending on the PL rates applied. For the mineral fertilizer treatments an average of 296 and 227 kg N ha^{-1} were recorded for the first and second years respectively. Consequently, an average 46% and 27% N was considered available in the first and second year respectively. Crop N uptake for the three rates of PL treatment averaged 331 kg N ha^{-1} and 267 kg N ha^{-1} in the first and second year respectively.

The P, K, Ca and Mg concentrations (Table 5) of plants grown either with PL or inorganic fertilizer were adequate for silage maize production. The values obtained in the first year were higher than in the second, perhaps again due to the different maize variety used in the second year. The plant P and K contents were not significantly influenced by the PL treatments in comparison with the mineral fertilizer. No significant differences were seen among any of these treatments in terms of the mean plant Ca and Mg concentrations over the two years of the study.

Discussion

The average dry matter production (Fig. 2) for the different treatments over the two years was higher than that reported by other authors (Cox and Cherney, 2001; Millner *et al.*, 2005). In general, during the two year of evaluation the dry matter production was similar between the treatments fertilized. The results therefore suggest that the different rates of PL applied have no adverse effect on maize yield, and show that the nutrient supply afforded by PL is sufficient for silage maize production. Thus, PL applied as a nutrient source with or without mineral fertilizer could replace the use of the latter at customary rates for silage maize (at least up to 20 Mg ha^{-1}).

Table 4. Nitrogen concentration, N uptake and apparent efficiency of N recovery (AENR) in the different treatments

Treatments	Silage maize-N (g kg^{-1})		N uptake (kg ha^{-1})		AENR (%)	
	2002-3	2003-4	2002-3	2003-4	2002-3	2003-4
T1	7.63c	5.65c	138.1c	138.7c	—	—
T2	9.30bc	7.75ab	290.6b	236.6b	50.8b	32.7a
T3	9.78ab	6.70bc	300.8ab	217.0b	40.7A	19.6B
T4	11.45a	8.00ab	389.6a	257.5ab	83.8a	39.6a
T5	10.38ab	7.58ab	273.4b	234.8ab	33.8A	26.3AB
T6	9.85ab	8.38a	330.2ab	309.4a	48.0A	42.7A
CV	13.31	14.72	20.89	19.1	—	—

For N concentration and uptake mean values within a column followed by a different letter are significantly different at $P \leq 0.05$. For AENR different cap letters in the same column indicate significant differences between treatments with high N dose, and different small letters in the same column indicate significant differences between treatments with low N dose at $P \leq 0.05$. CV: Coefficient of variation.

Table 5. Nutrient concentrations (g kg^{-1}) and nutrient uptake (kg ha^{-1})

Treatments	Nutrients amount (g kg^{-1})				Nutrients uptake (kg ha^{-1})			
	P	K	Ca	Mg	P_2O_5	K_2O	CaO	MgO
2002-2003								
T1	1.75	7.43b	2.25	1.33	71b	146b	48b	37b
T2	1.68	9.34ab	3.30	1.42	124ab	331a	133a	73a
T3	1.79	10.98ab	3.43	1.50	123ab	396a	145a	77a
T4	2.15	7.83b	2.43	1.48	167a	320a	115a	84a
T5	1.55	12.18a	4.00	1.73	97b	374a	142a	76a
T6	2.23	9.65ab	2.65	1.50	172a	381a	123a	83a
CV	24.64	23.67	44.72	14.84	31.69	20.05	37.07	15.58
2003-2004								
T1	1.33c	7.75	1.75	1.03	73c	221c	58b	40b
T2	1.63ab	8.30	1.88	1.18	114ab	299bc	80ab	60a
T3	1.43bc	8.90	1.98	0.98	106ab	345ab	87a	53ab
T4	1.68a	9.00	1.95	1.08	123ab	345ab	88a	42a
T5	1.55abc	8.15	1.90	0.98	103b	314b	74ab	38ab
T6	1.58ab	9.00	1.88	0.98	134a	398a	83a	43a
CV	9.94	11.37	12.89	10.65	18.30	17.20	22.30	19.10

Mean values within a column and year followed by a different letter are significantly different at $P \leq 0.05$. CV: Coefficient of variation.

The application of PL in the second year improved crop yield by about 10% with respect to the average obtained in the first year, suggesting the successive applications to have had a small cumulative effect. However, the increased yield may also have been related to a differential response of the maize variety used in each year (Heckman *et al*., 2003).

As expected, the lowest yields were always obtained with the control treatment. The dry matter values for T1 suggest that the soil of the experimental plot (when under irrigated conditions) has a high N-supply capacity of its own. In the second year the yield obtained for T1 was 6.68 Mg ha^{-1} higher than in the first year. This might also be attributable to the variety used in the second year, which had a lower N response than that used in the first year. In addition, the N supply in the second year may have been greater than in the first.

The N uptake and AENR for each treatment in both years of the study suggest that the available N supplied by the PL in the first year averaged 55% and for the second year 36%. On the whole, this is similar to that reported by other authors (Eghball, 2000; Binder *et al*., 2002; Eghball *et al*., 2004; Hermann and Taube, 2004; O'Neill *et al*., 2004; Powell *et al*., 2004; Warren *et al*., 2006), although lower than the N concentration reported by Nevens and Reheul (2003) and Eghball *et al*. (2004), and Millner *et al*. (2005) for the same crop grown with different organic amendments.

The AENR represents the fraction of N-fertilizer recovered in the harvested part of the plant; the unrecovered N fraction is in the unharvested parts, and the remainder becomes part of the soil biomass or is lost to leaching (Thomsen *et al*., 1997; Cogger *et al*., 2001). In this work, the AENR was used to provide an indirect assessment of the amount of plant-available N supplied by the mineral fertilizer and PL. The AENR obtained for the different treatments was always lower for the second year than for the first. This might be attributable to the operation of different environmental factors or to the different maize varieties used.

The AENR values obtained with the PL were, in all cases, higher than those obtained with the mineral fertilizer. This suggest that the N released from PL is an appropriate N supply for silage maize under the conditions in which the crop was grown. In addition, the N from PL becomes available for plant uptake over a long period following its application; this slow release minimizes the potential leaching of NO_3-N (Cogger *et al*., 2001; Rees and Castle, 2002).

Nitrogen recovery was least efficient at the highest application rate for both the mineral fertilizer and PL in both the first and second year. In contrast, the low rate showed best results for both fertiliser sources. In both years, the AENR obtained in the T6 treatment (PL without mineral fertiliser) was higher than those obtained with the other treatments providing the same N dose (T3 and T5), although the differences were not significant ($p \geq 0.05$).

Phosphorus, K, Ca and Mg uptake in both the first and second year were not directly related to the N rate applied, and no significant differences were observed between the two N sources. On the whole, the nutrient supply provided by the PL treatments was similar to that of the conventional fertilizer, suggesting PL to be an adequate nutrient source.

As conclusion, over the two years of this study, PL was found to be similar to mineral fertilizer in its ability to supply N and the other major nutrients to silage maize grown on a Typic Melanoxerands soil. Poultry manure could substitute synthetic fertilizer N for silage maize production at a single high rate, or at a medium or low rate with additional N applications. Further research is required to evaluate whether the increase in soil P seen with the PL T6 application is related to an increase in soluble P in surface water runoff. While PL could not be used to replace all other types of N fertilizer for silage maize in central Chile, it does have significant benefits when applied in combination with mineral fertilizer. These include yield improvements and increased N efficiency. In addition, using PL on agricultural soils could be a good waste recycling route for poultry producers, and provide a cheap yet valuable resource to farmers, allowing them to reduce their use of synthetic fertilizers.

References

ANON, 1997. The maize field handbook. 1997 Edition. KWS Huntseeds Ltd., Woolaston, UK.

ADEGBIDI H.G., BRIGGS R.D., 2003. Nitrogen mineralization of sewage sludge and composted poultry manure applied to willow in a greenhouse experiment. Biomass Bioenerg 25, 665-673.

BARBARICK K.A., IPPOLITO J.A., 2003. Termination of sewage biosolids applications affects wheat yield and other agronomic characteristics. Agron J 95, 1288-1294.

BINDER D.L., DOBERMANN A., SANDER D.H., CASSMAN K.G., 2002. Biosolids as nitrogen source for irrigated maize and rainfed sorghum. Soil Sci Soc Am J 66(2), 531-543.

COGGER C.G., BARY A.I., FRANSEN S.C., SULLIVAN D.M., 2001. Seven years of biosolids versus inorganic applications to tall fescue. J Environ Qual 30, 2188-2194.

COX W.J., CHERNEY D.J.R., 2001. Row spacing, plant density, and nitrogen effects on corn silage. Agron J 93, 597-602.

CUEVAS G., MARTÍNEZ F., WALTER I., 2003. Field-grown maize (*Zea mays* L.) with composted sewage sludge. Effects on soil and grain quality. Span J Agric Res 1(3), 111-119.

DAUDÉN A., QUÍLEZ D., 2004. Pig slurry versus mineral fertilization on corn yield and nitrate leaching in a Mediterranean irrigated environment. Eur J Agron 21(1), 7-19.

EGHBALL B., 2000. Nitrogen mineralization from field-applied beef cattle feedlot manure or compost. Soil Sci Soc Am J 64(6), 2024-2030.

EGHBALL B., GINTING D., GILLEY J.E., 2004. Residual effects of manure and compost applications on corn production and soil properties. Agron J 96(2), 442-447.

EVERS G.W., 2002. Ryegrass-bermudagrass production and nutrient uptake when combining nitrogen fertiliser with broiler litter. Agron J 94(4), 905-910.

FERGUSON R.B., NIENABER J.A., EIGENBERG R.A., WOODBURRY B.L., 2005. Long term effects of sustained beef feedlot manure application on soil nutrients, corn silage yield, and nutrient uptake. J Environ Qual 34, 1672-1681.

HECKMAN J.R., SIMS J.T., BEEGLE D.B., COALE F.J., HERBERT S.J., BRUULSEMA T.W., BAMKA W.J., 2003. Nutrient removal by corn grain harvest. Agron J 95(3), 587-591.

HERRMANN A., TAUBE F., 2004. The range of the critical nitrogen dilution curve for maize (*Zea mays* L.) can be extended until silage maturity. Agron J 96, 1131-1138.

INE, 2004a. Superficie sembrada con cereales, por especie. Santiago, Chile. Instituto Nacional de Estadística. Available on line in http:// www.ine.cl/ine/canales/chile_estadístico/compendio_estadístico/pdf/2005 [10 December, 2005]. [In Spanish].

INE, 2004b. Beneficio de aves por tipo y especies. Santiago, Chile. Instituto Nacional de Estadística. Available on line in http://www.ine.cl/ine/canales/chile_estadístico/compendio_estadístico/pdf/2005 [26 December, 2005]. [In Spanish].

MILLNER J.P., VILLAVER R., HARDACRE A.K., 2005. The yield and nutritive value of maize hybrids grown for silage. New Zeal J Agr Res 48, 101-108.

MUIR J.P., 2001. Effect of dairy compost application and plant maturity on forage kenaf cultivar fiber concentration and in sacco disappearance. Crop Sci 42, 248-254.

NEVENS F., REHEUL D., 2003. The application of vegetable, fruit and garden waste (VFG) compost in addition to cattle slurry in a silage maize monoculture: nitrogen availability and use. Eur J Agron 19(2), 189-203.

O'NEILL P.M., SHANAHAN J.F., SCHEPERS J.S., CALDWELL B., 2004. Agronomic responses of corn hybrids from different eras to deficit and adequate levels of water and nitrogen. Agron J 96(6), 1660-1667.

PARKINSON R.J., FULLER M.P., GROENHOF A.C., 1999. An evaluation of greenwaste compost for the production of forage maize (*Zea mays* L.). Compost Sci Util 7(1), 72-80.

PLÉNET D., LEMAIRE G., 2000. Relationships between dynamics of nitrogen uptake and dry matter accumula-

tion in maize crops. Determination of critical N concentration. Plant Soil 216, 65-82.
POWELL J.M., WU Z., KELLING K., CUSICK P., MUÑOZ G., 2004. Differential nitrogen-15 labelling of dairy manure components for nitrogen cycling studies. Agron J 96(2), 433-441.
REES R., CASTLE K., 2002. Nitrogen recovery in soils amended with organic manures combined with inorganic fertilisers. Agronomie 22, 739-746.
SAS INSTITUTE., 1989. Usage and reference. Version 6. 501 p. SAS Institute Inc., Cary, North Carolina, USA.
SHARPLEY A., 1996. Availability of residual phosphorous in manured soils. Soil Sci Soc Am J 60, 1459-1466.
SIMS J.T., WOLF D.C., 1994. Poultry waste management: agricultural and environmental issues. Adv Agron 52, 1-83.
SINGH A., BICUDO J.R., TINOCO A.L., TINOCO I.F., GATES R.S., CASEY K.D., PESCATORE A.J., 2004. Characterization of nutrients in built-up broiler litter using trench and random walk sampling methods. J Appl Poult Res 13, 426-432.
SULLIVAN D.M., BARY A.I., THOMAS D.R., FRANSEN S.C., COGGER C.G., 2002. Food waste compost effects on fertiliser nitrogen efficiency, available nitrogen, and tall fescue yield. Soil Sci Soc Am J 66, 154-161.
THOMSEN I.K, KJELLERUP V., JENSEN B., 1997. Crop uptake and leaching of ^{15}N applied in ruminant slurry with selectively labelled faeces and urine fractions. Plant Soil 197, 233-239.
USDA, 1994. Reference to soil taxonomy. USDA, Washington, D.C.
WARREN J.G., PHILLIPS S.B., MULLINS G.L., KEAHEY D., PENN C.J., 2006. Environmental and production consequences of using alum-amended poultry litter as a nutrient source for corn. J Environ Qual 35, 172-182.