MANURE MANAGEMENT

Effect of Swine Slurry on Alfalfa Production and on Tissue and Soil Nutrient Concentration

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ABSTRACT

Alfalfa (*Medicago sativa* L.) may not be the most suitable crop to utilize all the manure nutrients, but it may be the best crop available, especially when the crop is dormant. The objective of this research was to investigate the effect of swine (*Sus scrofa domesticus*) slurry manure on alfalfa yield and the concentration of nutrients in soil. A 2-yr field experiment was initiated in 2001 on two soils: a Typic Xerofluvent and a Calcixerolic Xerochrept. Soil mineral elements were extracted with ammonium bicarbonate diethylenetriaminepentaacetic acid, and initial extractable P and K were 16.7 and 6 mg P kg^{-1} and 152 and 103 mg K kg^{-1} for the two soils, respectively. There were four treatments: annual winter applications of 25 and 50 m^3 ha^{-1} of swine slurry manure, annual fertilization of 32.75 kg P ha^{-1} and 125 kg K ha^{-1}, and a no-manure or fertilizer control. Application of slurry manure in winter was not detrimental to the crop. Manure and fertilizer treatments increased alfalfa dry matter (DM) yield 37% on the low-fertility soil. There was no significant effect of manure or fertilizer on alfalfa DM yield on the Xerofluvent soil. Application of the slurry slightly increased the soil concentrations of P, Mg, Zn, and Fe in higher-fertility soils and copper in low-fertility soils. The 2-yr results suggest that the application of slurry in soils with low levels of trace elements, such as those used in the trials, does not produce a significant buildup of these elements that could lead to an environmental problem.

Land application of animal wastes to enhance crop production is an agricultural practice that has been used for centuries. To better utilize the manure as a fertilizer, and to reduce the risks of pollution, studies have been conducted to evaluate its use, particularly in crops such as maize (*Zea mays* L.) that can enhance the value of N contained in the slurry (Hatfield, 1998). Farmers know that the application of manure to crops such as maize may be the most efficient way to utilize all the manure nutrients. However, many producers do not have sufficient area of maize for slurry applications at agronomic rates or following recommended best management practices, and they need other crops to apply the slurry (Kelling and Schmitt, 1996). Increasingly, regulatory pressure aimed at reducing environmental problems, the introduction of systematic nutrient management planning, and related concerns over ground and surface water pollution are causing swine and dairy producers to reconsider their management strategies (Bodet et al., 2001; Soil and Water Conserv. Soc., 1998; Danés et al., 1995).

In several alfalfa-producing areas, alfalfa and maize are important irrigated crops, and swine growing is one of the main animal production activities. Alfalfa has become an alternative crop although alfalfa fields may not be the best possible location for manure applications. As reported by Kelling and Schmitt (1996) in Wisconsin, topdress applications of manure on alfalfa are often made because of necessity rather than choice. These may be the only fields available at some times of the year and, on many farms, the best environmental alternative (Kelling and Schmitt, 1996).

Manure application on alfalfa has been considered a risky management practice by many because it may cause plant injury or stand reduction of the alfalfa due to the salts contained in the manure and physical damage to the crowns during application, mainly in the wheel-track areas (Kelling and Schmitt, 1996; Lory et al., 2000). Slurry manure may also increase DM yields due to an increase in the weeds. This may occur at least in the first cutting because weeds can take better advantage of the N of the slurry (Kelling and Schmitt, 1996). In a study conducted in Massachusetts, the application of dairy manure to alfalfa at the low rate (112 kg N ha^{-1}) had no significant effect on DM yields, N accumulation in herbage, and soil NO_3–N at the 0- to 30-cm depth. The authors concluded that dairy manure can be applied to established alfalfa without any adverse impact on herbage production or soil water (Daliparthy et al., 1994). In Southern Europe, preliminary studies comparing mineral fertilization with swine slurry on alfalfa did not suggest differences in the forage DM yield or detrimental effects of the slurry to the crop (Mangado and Ameztoy, 1997; Domingo and Bosch, 2001).

Traditional fertilizer recommendations have consistently stated that N fertilizers do not need to be applied on alfalfa fields (Hannaway and Shuler, 1993). Alfalfa typically meets its N need through symbiotic N fixation but will preferentially utilize mineral N if it is available (Allos and Bartholomew, 1955, 1959; McAuliffe et al., 1958). Research into the effects of manure on alfalfa has shown that manure is increasingly being applied to alfalfa because of alfalfa's ability to recycle nutrients and its potential to extract nutrients from a significant

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Abbreviations: AB-DTPA, ammonium bicarbonate-diethylenetriaminepentaacetic acid; DM, dry matter.

depth. For example, alfalfa can recover nitrates that have started moving downward in the soil due to its deeper rooting zone (Schmitt et al., 1991, Blumenthal et al., 1999). Publications from several countries stress the importance of the slurry manure as a supplier of P and K. Their equivalence is normally 1 to 0.85 compared with chemical fertilizers. Consequently, P and K furnished by the manure can replace part or all of these elements provided by traditional mineral fertilizers (Bodet et al., 2001; Lory et al., 2000).

There have been concerns regarding the increasing concentrations of Zn and Cu in soils where agricultural wastes have been applied (Coppenet et al., 1993). This potential buildup is due to the common nutritional practice within the swine industry of formulating swine diets with high levels of trace elements (Spears et al., 1998).

Alleviation of potential N problems on other fields and the benefit of the other nutrients in the manure could provide a sufficient economic and environmental justification for using manure on alfalfa fields (Schmitt et al., 1991).

In the Ebro Valley in Spain, manure applications to alfalfa would increase the land available for spreading, improving the N balance and thus lessening the potential of nitrate leaching. There is an opportunity in this region to apply manure in winter when the crop is dormant and precipitation is rare (Lloveras, 2001). However, few data are available on the effects of swine slurry on the alfalfa crop and on soil nutrient evolution.

This study evaluated the effects of moderate amounts of swine slurry manure on irrigated alfalfa production and on tissue and soil nutrient concentration.

MATERIALS AND METHODS

The experiments were conducted over two growing seasons, 2001 and 2002, in two irrigated fields seeded with 'Aragón' alfalfa in the second and third year of production in Alcolea de Cinca (Alcolea) and Villanueva de Sigena (Villanueva). The sites (41°43′ N, 00°07′ E) are about 10 km apart and are located in the Ebro Valley of Spain. Mean annual temperatures for the 2001 and 2002 growing seasons were 13.8 and 14.3°C, respectively. The plots were flood-irrigated every 15 to 20 d, receiving a total of about 800 mm of water. Annual rainfall was less than half of this amount (274.1 mm in 2001 and 377 mm in 2002),

The soil in Alcolea is a Typic Xerofluvent. It is a deep, calcareous soil (1.5 m), with a $CaCO_3$ equivalent of 370 g kg^{-1}, a basic pH of 8.2 (water), and an organic matter concentration of 17 g kg^{-1}. It has a silt loam texture (131 g kg^{-1} of sand, 600 g kg^{-1} of silt, and 269 g kg^{-1} of clay) and is well drained, with a gravel layer of alluvial origin at about 1.5-m depth. From 30- to 60-cm depth, the soil has a sandy loam texture with a pH of 8.4 and a $CaCO_3$ equivalent of 250 g kg^{-1}. In Villanueva, the soil is a Calcixerolic Xerochrept. It has a clay loam texture (444 g kg^{-1} of sand, 266 g kg^{-1} of silt, and 290 g kg^{-1} of clay) and is well drained with a petrocalcic layer at 65- to 75-cm depth. The soil analysis (0- to 30-cm depth) presented a pH of 8.2 (water), organic matter of 15 g kg^{-1}, and a $CaCO_3$ equivalent of 350 g kg^{-1}. From 30- to 60-cm depth, the soil has a sandy loam texture with a pH of 8.4 and a $CaCO_3$ equivalent of 400 g kg^{-1}. Neither soil is saline.

The statistical design was a randomized block with three replications. The elemental plot size was 50 by 14 m in Alcolea and 110 by 14 m in Villanueva. The plots had been leveled previous to the seeding of alfalfa. In each location, two rates of swine slurry, 25 and 50 m^3 ha^{-1}, were applied annually at the end of January 2001 and 2002, when the crop was dormant, by a trained commercial applicator. These rates were considered low or moderate in the geographical area of the trials and are rates most commonly used in most crops. The slurry was spread, in one strip over each plot, over a width of 12 m, of which the central 6 m was used for forage yield and plant and soil mineral determinations.

The slurry treatments were compared with a control in which no slurry and no mineral fertilization were applied and with a fourth treatment with annual applications of 32.75 and 125 kg of P and K respectively, representing the average fertilizer applications in the area. The P and K fertilization treatment was not applied in 2001 in Alcolea.

Swine manure was obtained from a concrete pit of a neighboring farm. The average composition in N, P, and K in 2001 was 87, 23, and 55 g kg^{-1}, respectively, on an *as is* basis. In 2002, the composition was 55.9, 22.5, and 76.3 g kg^{-1} N, P, and K, respectively.

Nitrogen in the fresh sample of pig slurry was analyzed by the Kjeldahl method (Nelson and Sommers, 1973), and the P and K contents were analyzed according to the European Commission BCR Reference Materials (Quevauviller et al., 1996). Dry matter contents of the slurry were 47 kg m^{-3} in 2001 and 61 kg m^{-3} in 2002. Trace elements of the slurry were not determined, but the average values of Cu and Zn contents of the farms of the area are 567 and 1200 mg kg^{-1}, respectively (LAF, 1999).

Forage yield was determined by harvesting six subsamples of 1 by 6 m from each plot, and their averages per plot were used for statistical analyses. Five cuttings were harvested each year at the mid- to full-flowering state, except for the first and the last cut of the year when the crop does not flower because of the photoperiod. The first harvest was in about mid-April and the last in late October, with a period of about 30 d between harvests.

Insect control was achieved by two to four sprays per year of 0.1 kg ha^{-1} a.i. fenvalerate [cyano (3-phenoxyphenyl)methyl 4-cholo-α-(methylethyl)benzeacetate]. Weeds were controlled in the 2002 growing season by applying 1 kg ha^{-1} a.i. hexazinone [3-cyclohexyl-6-dimethylamino-1-methyl-1,3,5-triazine-2,4 (1*H*,3*H*)-dione] in January. The proportions of alfalfa and weeds were evaluated from four subsamples of 300 g per plot and through separation of alfalfa and weeds in the laboratory.

Four wet samples of herbage of 500 g were collected from each plot at each harvest for moisture determination and subsequent chemical analysis. Samples were dried at 70°C, and DM yields were calculated on this basis. Ground (1-mm screen) plant tissue samples were analyzed for several nutrients. Total N was analyzed by the Kjeldahl method (Nelson and Sommers, 1973), and K, Ca, P, Mg, B, Cu, Fe, Mn, and Zn contents were analyzed by inductively coupled argon plasma spectrophotometry (Polyscan 61E, Thermo Jarrell-Ash Corp., Franklin, MA), after the calcinated plant ashes had been digested with nitric acid (Mills and Jones, 1996).

Ten soil cores were taken from the 0- to 30-cm soil depths of each plot before fertilization and end of the trials to determine the evolution of the soil fertility elements. Soil mineral elements were extracted using ammonium bicarbonate-diethylenetriaminepentaacetic acid (AB-DTPA) (Soltanpour, 1991) and determined by inductively coupled argon plasma spectrophotometry (Polyscan 61E, Thermo Jarrell-Ash Corp., Franklin, MA).

The results of each experiment were analyzed separately and were subjected to analysis of variance with the General

Table 1. Alfalfa dry matter (DM) yield and weighted averages of its mineral concentrations under different rates of swine slurry manure and P and K (P–K) mineral fertilization. Data summarize the 2001 and 2002 growing seasons at Alcolea.

Nutrient source	Rate	DM yield	Alfalfa	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Na	Zn
		Mg ha^{-1}	g kg^{-1}							mg kg^{-1}					
							2001								
Control	0	12.6	859	36.9	3.2	29.7	18.0	2.6	2.9	46.2	10.4	183	29.7	2168	31.9
Manure	25 m^3 ha^{-1}	11.8	769	36.5	3.3	30.4	16.8	2.6	2.8	42.5	10.6	206	30.1	2242	34.5
Manure	50 m^3 ha^{-1}	13.6	808	36.2	3.3	30.4	17.2	2.7	3.0	43.9	11.1	202	30.9	2449	33.3
LSD (0.05)		NS†	NS	NS	NS	NS	0.9	NS	NS	NS	0.4	NS	NS	NS	NS
							2002								
Control	0	14.0	903	45.0	3.1	25.0	22.1	3.1	4.1	45.7	10.7	299	39.1	2953	28.9
Manure	25 m^3 ha^{-1}	15.6	899	43.0	3.0	25.6	22.0	3.1	4.2	45.6	11.2	289	38.8	2971	30.3
Manure	50 m^3 ha^{-1}	15.9	915	43.5	3.2	28.1	23.1	3.2	4.3	48.6	12.5	276	40.3	2829	32.5
P–K fertilizer	33/125 kg ha^{-1}	15.1	850	44.9	3.4	28.0	21.9	3.1	4.0	45.5	10.8	277	36.9	2774	31.1
LSD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS	1.3	NS	NS	NS	NS
							Total (2001 and 2002)								
Control	0	26.6	883	41.2	3.1	27.2	20.2	2.8	3.5	45.9	10.5	244	34.6	2587	30.2
Manure	25 m^3 ha^{-1}	27.4	843	40.3	3.2	27.7	19.9	2.9	3.6	44.3	10.9	254	35.1	2659	32.1
Manure	50 m^3 ha^{-1}	29.5	865	40.2	3.3	29.2	20.4	3.0	3.7	44.5	11.9	242	36.0	2649	32.9
LSD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS	0.8	NS	NS	NS	NS

† NS, nonsignificant.

Linear Model procedure of the Statistical Analysis System (SAS Inst., 1988). The two trials were analyzed separately because in Alcolea, one of the treatments, fertilization with P and K, was missing in 2001 and in the 2-yr total.

RESULTS AND DISCUSSION

Forage Yields

The effects of swine slurry manure varied according to the location (Tables 1 and 2). Mean 2-yr total DM yield in Alcolea was 27.8 Mg ha^{-1} whereas in Villanueva, it was 19.6 Mg ha^{-1}. Lower yields obtained in Villanueva could be partially due to problems in the irrigation system (less water than expected) during regrowth after the first harvest of 2001, contributing to low yields in the second harvest. However, total yields were similar for both years at this location.

Control DM yield was significantly less than other treatments, but there were no differences among manure and fertilizer treatments at the Villanueva location (Table 2). Fertilization of alfalfa with manure or mineral fertilizer increased harvested DM 37%. There were no significant differences among treatments at the Alcolea location (Table 2).

The Villanueva results suggest the beneficial effects of the P and K on alfalfa, a crop that normally requires high levels of both elements (Lanyon and Griffith, 1988; Undersander et al., 1994). The similar effect of mineral P and K and the manure treatments shows the beneficial effects of swine slurry as a fertilizer for alfalfa and implied that the P and K content of the manure was its primary benefit to the Villanueva alfalfa crop.

In our trials, the amounts of swine slurry applied were not detrimental to the alfalfa DM yields in any year and location, in agreement with suggestions from preliminary reports (Mangado and Ameztoy, 1997; Domingo and Bosch, 2001). Research with higher amounts of liquid dairy manure, from 44 to 132 m^3 ha^{-1}, also suggested that liquid dairy manure could be applied to alfalfa without any adverse effects on herbage yield or weed incidence and with no economic risk on productivity (Daliparthy et al., 1995).

Table 2. Alfalfa dry matter (DM) yield and weighted averages of its mineral concentrations under different rates of swine slurry manure and P and K (P–K) mineral fertilization. Data summarize the 2001 and 2002 growing seasons at Villanueva.

Nutrient source	Rate	DM yield	Alfalfa	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Na	Zn
		Mg ha^{-1}	g kg^{-1}							mg kg^{-1}					
							2001								
Control	0	8.0	743	30.6	1.8	13.1	21.4	2.9	2.6	42.0	8.28	193	27.3	4669	20.2
Manure	25 m^3 ha^{-1}	10.2	688	30.4	2.3	15.8	19.1	3.0	2.8	41.0	9.64	169	26.4	6898	22.0
Manure	50 m^3 ha^{-1}	10.4	739	31.7	2.2	16.0	19.3	2.8	2.4	40.5	9.67	149	25.4	5380	22.6
P–K fertilizer	33/125 kg ha^{-1}	10.5	769	31.7	2.3	16.9	20.1	2.8	2.2	39.2	7.81	159	24.6	3720	16.5
LSD (0.05)		NS†	NS	NS	0.2	2.1	1.1	NS	NS	NS	1.4	NS	NS	NS	2.3
							2002								
Control	0	7.0	951	37.8	2.0	13.6	26.1	3.1	4.4	59.5	11.2	244	43.8	3392	29.3
Manure	25 m^3 ha^{-1}	10.8	973	40.7	2.4	17.3	20.9	2.8	4.2	50.2	11.1	220	37.5	3149	27.2
Manure	50 m^3 ha^{-1}	11.3	950	41.5	2.6	19.2	20.3	2.6	4.3	49.5	10.7	219	39.2	2374	28.3
P–K fertilizer	33/125 kg ha^{-1}	10.0	969	39.6	2.6	16.1	21.3	2.9	4.3	52.6	9.7	238	50.2	3114	22.6
LSD (0.05)		2.8	NS	NS	0.3	3.1	NS	0.2	NS	NS	1.2	NS	NS	NS	2.7
							Total (2001 and 2002)								
Control	0	15.4	837	34.1	1.9	13.4	23.7	3.0	3.5	50.3	9.7	215	35.0	4075	24.5
Manure	25 m^3 ha^{-1}	20.9	811	35.8	2.4	16.5	20.0	2.9	3.6	45.7	10.4	192	32.1	5013	24.6
Manure	50 m^3 ha^{-1}	21.7	842	36.8	2.4	17.7	19.8	2.7	3.4	45.1	10.2	184	32.6	3823	25.5
P–K fertilizer	33/125 kg ha^{-1}	20.4	851	35.6	2.5	16.6	20.8	2.9	3.2	45.4	8.7	191	36.2	3444	19.3
LSD (0.05)		4.9	NS	NS	0.2	2.1	2.5	NS	NS	NS	0.7	NS	NS	NS	2.3

† NS, nonsignificant.

In the experiments reported here, the wheel tracks of the applicators were observed in the plots for several weeks after the application. However, it was impossible to distinguish the wheel tracks from the rest of the field after the spring regrowth in any field or year.

In the first year of the experiment, in Alcolea (high-fertility soils), the proportion of the alfalfa in the herbage seemed to decrease, although not significantly, with the application of 25 and 50 m^3 ha^{-1} of slurry, going from 769 and 808 g kg^{-1} of alfalfa, respectively, to 859 g kg^{-1} with no slurry (Table 1). This suggested, as reported by others, that the N content of the slurry might favor weed growth and competition (Schmitt et al., 1991; Kelling and Schmitt, 1996). However, in the second growing season, when herbicide was applied in winter, the proportion of alfalfa in the subsequent spring regrowth increased. No differences were observed in weed proportion with the application of slurry in either year. The results suggest that the beneficial effect of the slurry was not due to a weed increase but to the fertilizer effects of the slurry, possibly P and K.

Plant Composition

Mineral concentration of alfalfa varied depending on the location. The weighted average concentrations of P, K, Cu, and Zn were higher in Alcolea than in Villanueva (Tables 1 and 2). In Villanueva, with a low soil concentration of P and K, the application of the slurry increased the alfalfa contents of P and K whereas there was no effect at Alcolea. The increase in plant concentration of P and K observed at Villanueva could be partially due to the lower initial soil extractable levels of these nutrients in this location compared with those found in Alcolea. Reports from other areas show that the plant responses were correlated with soil extractable quantities of P and K (James et al., 1995; Lanyon and Griffith, 1988). The average values of P and K of the whole-plant alfalfa, obtained in our experiments, are considered adequate in Alcolea, but they are at the critical levels for P and K in Villanueva according to the values summarized by Kelling and Matocha (1990). Nutrient sufficiency range is >3 g kg^{-1} for P and from 14 to 30 g kg^{-1} for K (Kelling and Matocha, 1990).

The application of the slurry increased the plant concentration of Cu, in both locations, whereas the concentration of Zn only increased in Villanueva (Tables 1 and 2). These results are in agreement with studies showing that the application of swine manure produces surpluses of Cu and Zn, leading to increases in soil and as a consequence plant concentrations of Cu and Zn (Chaussod et al., 1997; Coppenet et al., 1993).

Soil Nutrient Evolution and Balance of Nutrients

The initial and final soil mineral concentrations for each location are presented in Tables 3 and 4.

At the end of the 2 yr, the application of the slurry at the high rate increased the soil concentrations of P, Mg, Zn, and Fe in Alcolea. In Villanueva, only the concentration of Cu was significantly affected by the slurry applications. Runoff losses from the fields were not considered because the fields are regularly leveled every 4 to 5 yr.

Table 3. Soil mineral concentration, Alcolea.

Nutrient source	Rate	N	P	K	Mg	Mn	Zn	Cu	Fe	Na
		mg kg^{-1}								
Initiation of the experiment, October 2000										
Control	0	–	14.6	150	128	2.3	3.1	5.7	27.8	173
Manure	25 m^3 ha^{-1}	–	16.9	153	126	3.1	3.4	5.9	31.5	172
Manure	50 m^3 ha^{-1}	–	15.5	151	127	2.8	3.5	5.8	30.4	193
P–K fertilizer	33/125 kg ha^{-1}	–	18.6	155	127	3.1	3.4	6.0	31.5	165
End of the experiment, October 2002										
Control	0	11.3	13.3	122	117	6.0	3.8	7.0	38.3	178
Manure	25 m^3 ha^{-1}	12.0	16.3	114	118	6.3	3.9	6.7	39.3	174
Manure	50 m^3 ha^{-1}	15.0	25.3	133	127	6.7	4.7	7.7	46.7	184
P–K fertilizer	33/125 kg ha^{-1}	13.0	19.7	114	115	5.7	4.0	7.2	40.3	167
LSD (0.05)		NS†	4.8	NS	6	NS	1.0	NS	4.3	NS

† NS, nonsignificant.

The balance of the K (Table 5) was negative for all treatments at both locations, showing that the amounts of swine manure applied were not sufficient to cover the needs of the alfalfa, whose average annual extractions ranged from 160.7 to 390 kg K ha^{-1} in Villanueva and Alcolea, respectively. Consequently, lower final K soil concentrations were observed (Tables 3 and 4). However, the P needs, whose average annual extractions ranged from 23.0 to 44.7 kg P ha^{-1} in Villanueva and Alcolea, respectively, were met by the application of 50 m^3 ha^{-1} of slurry. Consequently, the increase in soil P at the end of the trials at Alcolea, with the treatment of 50 m^3 ha^{-1}, reflects the positive balance of this treatment (Table 3). At Villanueva, with lower soil fertility and lower DM yields, the nutrient balance for P was positive (Table 5), but it was not well reflected in the final P soil concentrations, possibly because, in this soil with high level of Ca, the P could be tied up (Sharpley, 2000).

As for the trace elements, the initial soil levels of extractable Fe, Mn, Cu, and Zn depended on the location, with higher concentrations of these elements at Alcolea than at Villanueva. The observed soil values for Cu in Villanueva are higher than those observed in the traditional cropping systems [alfalfa–maize–wheat (*Triticum aestivum* L.)] of the Ebro Valley but lower than the reports found in very intensive horticultural areas of the Valley (Virgili et al., 2001) or California (Chang and Page, 2000). The applications of slurry significantly affected the levels of available trace elements, such as Cu, Zn, and Fe, depending on the soil fertility

Table 4. Soil mineral concentration, Villanueva.

Nutrient source	Rate	N	P	K	Mg	Mn	Zn	Cu	Fe	Na
		mg kg^{-1}								
Initiation of the experiment, October 2000										
Control	0	–	4.2	103	63.5	5.6	1.4	1.3	19.1	100
Manure	25 m^3 ha^{-1}	–	8	90	66.7	5.7	1.6	1.3	24.6	115
Manure	50 m^3 ha^{-1}	–	4	100	65.0	5.6	2.3	1.5	20.1	62
P–K fertilizer	33/125 kg ha^{-1}	–	8	120	62.8	6.6	2.3	2.0	20.0	82
End of the experiment, October 2002										
Control	0	8.0	3.3	83	61.0	6.0	1.8	1.3	25.7	70
Manure	25 m^3 ha^{-1}	9.3	4.3	66	69.3	6.7	1.6	1.6	33.0	74
Manure	50 m^3 ha^{-1}	7.0	3.3	85	72.0	5.3	1.7	1.5	28.3	124
P–K fertilizer	33/125 kg ha^{-1}	8.0	5.7	81	58.0	6.0	1.4	1.2	28.7	74
LSD (0.05)		NS†	NS	NS	NS	NS	NS	0.2	NS	NS

† NS, nonsignificant.

Table 5. Balance of nutrients, total for 2001 and 2002.

		N			P			K		
Nutrient source	Rate	Inputs	Uptake	Balance	Inputs	Uptake	Balance	Inputs	Uptake	Balance
		kg ha^{-1}								
					Alcolea					
Control	0	0	1098	−1098	0	84.4	−84.4	0	724	−724
Manure	25 m^3 ha^{-1}	187.4	1104	−916.6	61.3	87.2	−25.9	180.9	758	−577.1
Manure	50 m^3 ha^{-1}	374.8	1185	−810.2	122.6	96.9	25.7	361.8	861	−499.2
LSD (0.05)		–	NS†	78.8	–	9.5	9.5	–	49	49.7
					Villanueva					
Control	0	0	528	−528	0	30.3	−30.3	0	210	−210
Manure	25 m^3 ha^{-1}	187.4	747	−559.6	61.3	49.8	11.5	180.9	344	−163.1
Manure	50 m^3 ha^{-1}	374.8	802	−427.2	122.6	53.5	69.1	361.8	389	−27.2
P–K fertilizer	33/125 kg ha^{-1}	0	728	−728	65.5	51.0	14.5	250	343	−93
LSD (0.05)		–	184	184.2	–	14.3	14.3	–	105	105.1

† NS, nonsignificant.

level. At Alcolea, with higher soil fertility, the concentration of Zn and Fe significantly increased with slurry application, whereas at Villanueva, Cu was the only element affected.

The increase in Cu and Zn levels with the application of swine slurry has been reported to be of the order of 0.25 to 2 mg kg^{-1} yr^{-1} in soils of northwest France receiving annual applications of swine slurry of 50 m^3 ha^{-1} or higher for at least 15 yr (Bourrelier and Berthelin, 1998). In our study, the rates for Cu observed in Villanueva were at most, half of those reported in France, and there was no increase at Alcolea. One reason could be that in areas with long alfalfa growing seasons, such as those where experiments were conducted, and good forage yields, alfalfa can remove larger amounts of trace elements from soils (100 g ha^{-1} yr^{-1} of Cu and Zn) (Chang and Page, 2000).

The results of our experiments suggest that, with the moderate amounts of swine slurry applied, extractable levels of trace elements accumulate very slowly in alfalfa fields with high levels of $CaCO_3$, and alfalfa can be used as a crop to dispose of the slurry. These low rates of accumulation are not likely to interfere with agriculture.

Alfalfa can be a major sink for recycling (Undersander et al., 1994; Van Horn and Hall, 1997), with average annual extractions of 350 and 564 kg N ha^{-1}, in Villanueva and Alcolea, respectively.

The extractions of N were higher than the inputs (Table 5), showing a negative budget that went from 427 to 916.6 kg N ha^{-1} for the treatments receiving N and consequently helping to reduce the possible N water pollution. It is known that the amount of N symbiotically fixed is inversely related to the amount of N available from other sources (Hannaway and Shuler, 1993). Alfalfa preferentially uses N from the soil and from applied sources such as manure and uses N fixation to meet any additional N need.

CONCLUSIONS

Annual applications of up to 50 m^3 ha^{-1} of swine slurry were not detrimental to the alfalfa crop but increased DM yields by at least 36% in soils with low nutrient fertility levels (6 mg kg^{-1} and 103 mg kg^{-1} of AB-DTPA extractable P and K, respectively) compared with nonfertilized plots. In soils with better fertility (16.7 mg kg^{-1} of extractable P and 152.5 mg kg^{-1} of extractable K), the application of swine slurry did not decrease the DM compared with the untreated plots.

The application of slurry increased the soil concentrations of extractable Cu and Zn in one trial each. However, the results suggested that in soils with low levels of trace elements, a 2-yr application of swine slurry did not produce a significant buildup of these elements that could lead to an environmental problem.

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