Efficiency of Organic Nitrogen Fertilization of Potato in Northeast Portugal

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Abstract

The study was conducted over a 4 year period with the purpose of measuring N mineralization using an *in situ* incubation technique, following the application of farmyard manure, poultry manure or municipal solid waste. The results varied from –10 % (net immobilization) to +28 % (net mineralization) in relation to the total organic N applied. N fluxes were assessed through plant N analysis during the growing season and through determination of potato tuber dry weight (TDW), N uptake by tubers and the apparent N recovery (ANR) of added N at harvest. Organic material applications slightly increased TDW above the control treatment (9 to 25%), although the results indicate a shortage of N, where no N was added to the crop. The effect of organic fertilization on N uptake by tubers was also limited. Petiole nitrate concentration and estimated net N mineralization were in agreement with trends in TDW and N uptake by tubers, with no differences in soil N availability between the control and organic treatments. Values of ANR were particularly low, ranging from 4 to 23 %. The results suggest that caution is needed when judging the contribution of organic fertilization to N nutrition of crops, which have a short growing season. Synchronization between N release and plant uptake is discussed.

INTRODUCTION

Farmyard manures have been utilized for centuries to maintain or increase the fertility of cropped soils. Nowadays, many conventional farms are interested in their use, particularly for vegetable production. At the same time there is an incentive for the application of organic materials to crops due to (i) increased availability of processed and marketed off-farm residues, (ii) increased environmental concern, promoting the utilization of organic waste rather than its disposal in landfills, and (iii) the development and effort put into organic farming.

The interest in organic fertilizers and amendments is due to their organic matter and nutrient content. The effect of organic matter is mainly due to the improvement of the physical (Schjønning et al., 1994; Benbi et al., 1998) and electrochemical (MacCarthy et al., 1990) properties of soils, often related to soil remediation and soil reclamation. In relation to nutrient supply, application of organic residues may reduce the amount of mineral fertilization required, and so consequently information is needed to quantify nutrient availability from organic sources (Brady and Weil, 1996), since environmental and economic pressure on agriculture has prompted farmers to make more efficient use of nutrients.

Nitrogen management practices and its fate in soil are particularly important since this nutrient is associated with environmental problems, including pollution of ground and surface waters (Magdoff et al., 1997). N mineralization-immobilization turnover (MIT) depends on the chemical composition, C/N ratio and decomposability indices of the organic materials added to the soil (Vigil and Kissel, 1991; Janssen, 1996). Net mineralization increases N availability to plants and, therefore, should increase yield and reduce the need for chemical fertilizer for optimal crop production. On the contrary, N immobilization temporarily limits the availability of mineral forms and reduces the efficiency of the inorganic fertilizer (Braakhekke et al., 1993). Aside from the overall balance of MIT, the synchronization between N supply from organic sources and crop demand is crucial for the efficient use of the applied N. Thus, organic inputs must be well timed to contribute to an efficient use of N (Mengel, 1996).

Although incubations and chemical methods have been tested, a reliable laboratory method to assess the rate and pattern of N mineralization is not available (Douglas and Magdoff, 1991) due to the complexity of the mineralization processes (Jarvis et al., 1996). Consequently, the rates of N mineralization from organic sources are not well known and uncertainties occur when calculating N application, leading to the possibility of underfertilization or excessive nitrate leaching. A field experiment was carried using three organic materials as sources of N for potato, and field measurements of N mineralization were made using an in situ incubation technique. Yield, N nutritional status during the growing season, N uptake and apparent N recovery were measured during the growing season. The organic materials were traditional cattle farmyard manure, off-farm manure from poultry and non-agriculture residue from municipal solid wastes.

MATERIAL AND METHODS

The field experiments were conducted over a four year period (1995-1998) at Bragança, Northeast Portugal. Five treatments consisting of cattle farmyard manure (FYM), fresh poultry manure (PM), municipal solid waste compost (MSW), urea and a control (non-N fertilization), organized in a block design with three replicates, were set up on a loamy eutric Fluvisol, with an organic matter content of about 15 g kg^{-1}. Urea and organic materials were applied at a rate equivalent to 100 kg N ha^{-1} and incorporated to a depth of 14 cm at planting time (Tables 1 and 2). Potato (*Solanum tuberosum* L. cv. Désirée) was used as test crop since it is considered to be particularly responsive to manures (Holliday et al., 1965). The crop was irrigated and was integrated into a 4-yr rotation (3-yr. maize, 1-yr. potato), using *Triticosecale* spp. as catch crop during the winters. Colorado potato beetle (*Leptinotarsa decemlineata*) and blight (*Phytophthora infestans*) were controlled using integrated pest management.

A sequential *in situ* coring technique was used to measure N mineralization during the growing season. The procedure was similar to that used by Hatch *et al*. (1990), but without the addition of acetylene as nitrification inhibitor. Six soil cores were taken with PVC tubes (14 cm high, 32 mm id) and placed in closed 1 L glass jars in 0.15 m deep holes in the ground adjacent to the experimental plots and incubated for periods of about 14 days. The sum of the fortnightly changes in inorganic N during the growing season, about 112 days, was used to estimate net N mineralization. Soil mineral nitrogen (SMN) was determined in non-incubated and incubated fresh samples with KCl 2 *M* (ratio 1:5). The concentration of $N\text{-}NH_4^+$ was analyzed by Berthelot reaction and $N\text{-}NO_3^-$ by the Griess-Ilosvay reagent after reduction in a Cd column (Houba et al., 1989), both by molecular absorption spectroscopy in a segmented flow analysis system.

At harvest, relative yield was calculated based on tuber dry weight (TDW) of the commercial class (∅>35 mm). N nutritional status of the plants during the growing season was evaluated by the nitrate concentration at 15-20 days after emergence (DAE) in the petioles of the youngest fully-expanded leaf (Mills and Jones, 1996). At harvest, total N tuber concentration was determined by wet digestion according to Novozamsky et al. (1983). The apparent N recovery (ANR) was calculated by the difference method (Tyler et al., 1983), taking into account the control and each organic or urea treatment.

RESULTS AND DISCUSSION

The N mineralized over 112 days is presented in Table 3. Over the four years, N mineralization in the control treatment was fairly constant, with an average mineralization rate of 0.71 kg N $ha^{-1}day^{-1}$ at a depth of 0.14 m, showing a steady release of N from soil organic matter as a result of homogeneity of soil characteristics and previous crop effects among fields and years. The amounts of N mineralized in the soil after the addition of PM were significantly higher than those observed for the control, except for 1995. Application of FYM and MSW resulted in similar N release values in each of these two treatments, which did not differ from the control treatment.

The results show minimum values of –10 % (net immobilization) for MSW in 1996 and maximum of 28 % (net mineralization) for PM in 1997 and 1998, in relation to the total N applied in organic forms. The composition of organic residues was widely variable (Table 2) and N mineralization was generally related to the C:N ratio of the organic materials, as referred by Whitmore and Groot (1994), and to its mineral N concentration, which may strongly modify the MIT balance (Mary et al., 1996), which was in agreement with the observations of Chadwick et al. (1997) and Coutinho et al. (1998).

The modest effect of manuring on the amount of N released is also reflected in SMN availability to the crop during the growing season, as shown for 1997 in Figure 1, with similar results in the other 3 years. Amongst the organic treatments, significant differences, compared to the control occur only up to 35 DAP, and even so only the plots which received PM showed the capacity to maintain higher values than the control. As expected, N availability with urea treatment was much higher during this period and its sharp drop can be explained by microbial immobilization, plant uptake and leaching, since heavy precipitation (50 – 90 mm) occurred after planting. At 49 DAP no differences in SMN were observed among the five treatments. Average residual soil mineral N after harvest in all treatments was about 6 mg kg^{-1}.

The concentration of NO_3^- in the petioles was significantly higher using urea than for the control treatment (Table 3). Nitrate is considered to be a sensitive parameter for the evaluation of the N status of the plant during the growing season (Loon *et al*., 1987), and related to final yield (Rodrigues *et al*., 1998). Throughout the 4 year period, the application of urea led to significant increases in TDW relative to the control treatment (Figure 2). Therefore, both parameters clearly indicate a shortage of N, where the supply relies on the release of N from soil organic matter, and where no additional N is added.

In spite of this apparent N shortage of N, added organic materials gave only a slightly increased TDW compared to the control (Figure 2), this is in agreement with the *in situ* mineralization results. Differences were significant only for FYM in 1995, and PM in 1996 and 1997. On average, PM application gave the highest yield: 87 % of relative TDW, against 81, 78 and 71% for FYM, MSW and control respectively, although there was high variability between years. Limited yield response to FYM was also reported by Goffart et al. (1997), this was explained by the C:N ratio of the FYM and the consequent lack of N mineralization. However, no adverse effect of MSW on yield was noticed when compared with FYM.

Among organic treatments, NO_3^- concentration in the petioles was higher for PM, except in 1995. Application of FYM and MSW resulted in similar values, which did not differ from the control treatment (Table 3), this same pattern was also observed for accumulated N mineralization (Table 3) and SMN (Figure 1). N uptake by tubers (Figure 3) also showed the same trend, although the differences amongst treatments appear to be greater than those observed for TDW. Low yields were related to lower tuber N concentration, probably as a consequence of the N deficit. As a consequence of low N release, low efficiency of the organic materials in N nutrition, low nitrogen uptake and low yields, the values of ANR for the organic N are also low (Table 4).

During the 4 year period, FYM, PM and MSW showed average ANR values of 4, 23 and 6 % respectively. These values are particularly poor; potato however, is considered to be an inefficient crop in using and translocating N (Joern and Vitosh, 1995a,b), which may explain the average value of 49 % for urea in this low input system of 100 kg N ha^{-1}. Other studies have also shown a low efficiency in similar organic fertilizers with corn (Schröder and Dilz, 1987; Grignani and Acutis, 1994) vegetable crops (Brito and Hadley, 1993), and potato (Rodrigues and Coutinho, 1996).

N requirement for potatoes appears to be critical early in the season (Westterman and Kleinkopf, 1985) and this may explain why some organic treatments, which released their N more quickly, had the ability to increase yield. In this experiment the application of exclusively organic materials was unable to supply the potatoes demand for N. The same may also be true for similar vegetable crops, which do not produce high yields in soils with a low or medium SMN baseline. Moreover, continuing N mineralization after the end of growing season, in addition to any crop residues, may increase the risk of losses by leaching and denitrification if no following crop is grown and no other control is practiced.

CONCLUSIONS

The modest effect of manuring on yield is confirmed by the low NO_3^- concentration in the petioles, and this is in agreement with the differences in the amounts of N mineralized and available as SMN from the different organic sources.

The variability in the composition of the organic fertilizers and amendments, and their consequent effect on SMN makes it particularly important to develop quick and reliable tests for estimating the behavior of manures under field conditions, so that they may be used to benefit agriculture.

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Tables

Table 1. Manuring and crop planting and harvest dates during the experimental period

year	manuring	potato planting	potato harvest	tritic. planting	tritic. harvest
1995	4 Jun	5 Jun	10 Oct	19 Oct	22 Apr (96)
1996	27 May	28 May	18 Sep	20 Oct	24 Apr (97)
1997	27 May	28 May	24 Sep	23 Jan	23 Apr (98)
1998	20 May	21 May	28 Sep	21 Oct	28 Apr (99)

Table 2. Some characteristics of the organic materials under study

	N kjeldhal (g kg^{-1})				C:N ratio				mineral N (mg kg^{-1})			
	1995	1996	1997	1998	1995	1996	1997	1998	1995	1996	1997	1998
FYM	27	12	17	19	10.7	11.6	10.0	11.3	634	323	566	310
PM	17	40	35	30	7.9	4.7	7.0	6.5	855	1436	2320	1118
MSW	15	17	22	14	14.9	14.7	11.5	12.1	395	237	718	183

Table 3. Accumulated N mineralization during the growing season and effect of urea and organic material application on petiole NO_3^- concentration at 15-20 DAE

	accumulated N in soil (mg kg^{-1})				petiole NO_3^- (g kg^{-1}DM)			
	1995	1996	1997	1998	1995	1996	1997	1998
control	55.2[a*]	64.2[b]	41.5[b]	50.8[b]	65[b*]	65[c]	32[c]	63[bc]
urea	-	-	-	-	113[a]	118[a]	122[a]	101[a]
FYM	53.7[a]	63.7[b]	45.1[ab]	50.7[b]	76[b]	77[c]	20[c]	55[c]
PM	51.4[a]	75.8[a]	59.5[a]	69.6[a]	70[b]	97[b]	53[b]	76[b]
MSW	55.2[a]	57.6[b]	54.7[ab]	60.6[ab]	78[b]	68[c]	23[c]	45[c]

*within each year, mean values with the same letter do not differ significantly (P<0.05) by Fisher's LSD test

Table 4. Values of apparent nitrogen recovery (%) for the urea and the organic materials applied to the potato crop

	1995	1996	1997	1998
urea	39.5	57.9	59.0	40.7
FYM	10.3	1.7	-6.1	10.7
PM	6.4	32.1	32.6	20.3
MSW	11.2	-0.4	6.8	5.9

Figures

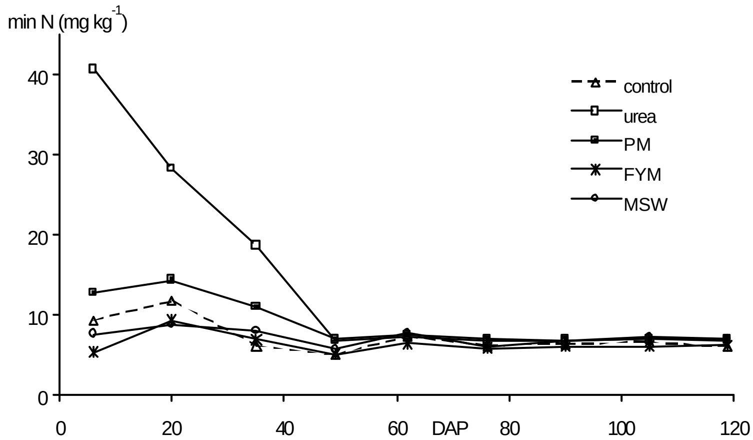
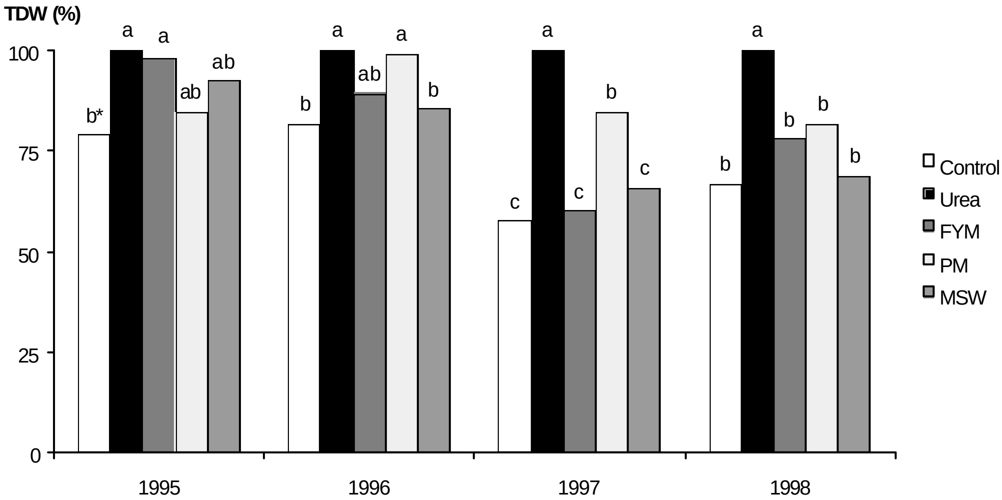
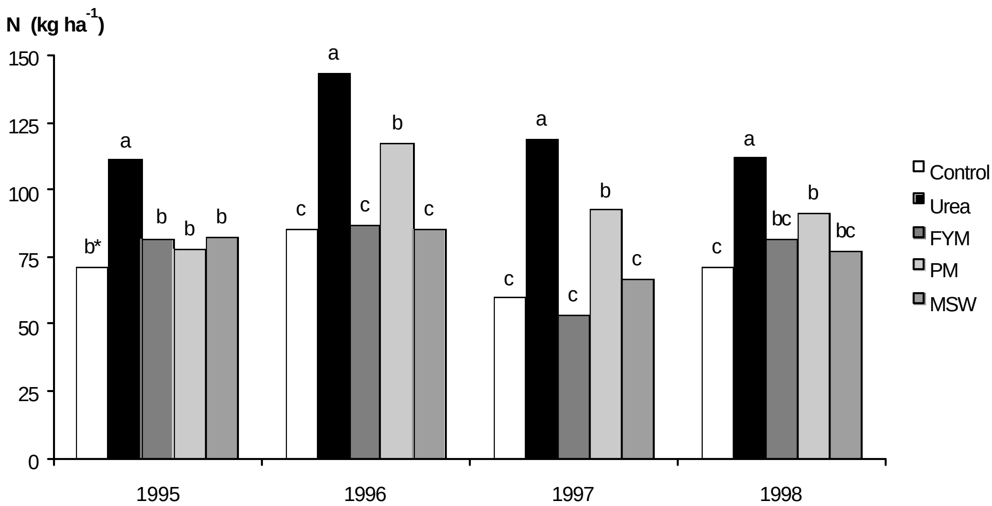


Fig. 1. Soil mineral N concentration (0-14 cm) during the growing season – 1997 ($LSD_{0.05}$=1.9)



*within each year, mean values with the same letter do not differ significantly (P<0.05) by Fisher's LSD test

Fig. 2. Effect of urea and organic material application on relative tuber dry weight (%TDW). Maximum yield = 24.7 (1995), 48.8 (1996), 42.1 (1997) and 45.1 t ha^{-1} (1998)



*within each year, mean values with the same letter do not differ significantly (P<0.05) by Fisher's LSD test

Fig. 3. Effect of urea and organic material application on N uptake by tubers