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A Low Environmental Impact System for Fertirrigation of Maize with Cattle Slurry

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Abstract

The applicability of an alternative system for managing and distributing cattle slurry during irrigation on maize was evaluated. An experiment was carried out by equipping a traveller boom with drop tubes and fed from a hose-reel machine. The new system was used for the distribution of the liquid separated fraction of slurry mixed with irrigation water (fertigation) on the soil surface between the rows of the crop. This system was compared with the conventional management system, utilizing a tank wagon equipped with splash plate for slurry application and a fixed irrigation system for irrigation. Analysis on leaching water samples indicate that the quality of percolation water is better due to a reduction in nitrate nitrogen losses. Besides, this alternative technique reduces the emissions of ammonia in the air and consequently the diffusion of ammonia in the atmosphere.

Keywords: traveller boom, irrigation, ammonia diffusion, nitrogen leaching, CropSyst model

1 Introduction

The most evident negative effect of slurry distribution is concern nitrogen losses in the environment, since this element is easily leached due to the high solubility of its nitrate form. Nitrogen losses may result dangerous for water bodies eutrophication and human health [43]. The quantity of nitrogen lost by leaching mainly depends on soil nitrate concentration and water drainage in the soil layers [37]. Evidence shows that seasonal management, soil tillage, fertilization, soils characteristics, crop potential absorption, irrigations and rain are likely to affect these losses [4, 6, 7, 10, 15, 20, 22, 33, 34].

In order to reduce the impact of this phenomenon it is important to maximize nitrogen crop interception; such aim is achievable distributing fertilizers in correct amount when crops need them. Fertigation can comply with this objective and consequently pursue the reduction of nitrogen losses [5, 15, 26]. Even the application of slurry by fertigation has a positive effect on the reduction of environmental impact [23]. Such a procedure is likely to reduce ammonia emission and seepage into groundwater and decrease fertilizers use. But, as regards cattle slurry, the impossibility to apply them using drip irrigation system and the necessity to empty the tanks in specific times because of their capacity limit, make very difficult the management of doses and the maximization of crop interception.

The increasing expansion of urbanized areas is likely to make people complain about smells due to diffusion from livestock farms [29, 40]. Besides, the slurry spreading causes ammonia emissions which reduces available nitrogen for plants and produces pollution. Ammonia is considered the major cause of acid rain [27], and its transformation to N_2O improves greenhouse gases stock [13]. Since agriculture is responsible for 90% of ammonium nitrogen emissions into the atmosphere, while up to 80% comes from livestock production, it can be argued that they both play a considerable role in air pollution [12, 28, 41, 42]. The quantity of ammonia lost by volatilization, after slurry application, mainly depends on physical and chemical characteristics of slurry, physical and chemical properties of soil, weather conditions, method and doses of application [2, 24, 35]. In particular, evidences show that the most of ammonia emissions take place in the first days after application [11, 29, 32]. Particularly problematic is the distribution of cattle slurry in the cultivated areas of the high Veneto plain (Northern Italy) where the widespread livestock farming produces big amounts of manure that need to be disposed of. Slurry is usually applied in spring and in autumn, when most precipitation occurs, encouraging nutrients leaching; summer application, which would favor nutrient mineralization and plant uptake in a key period, is usually not possible as forage crops (mostly maize) are present in the fields.

Irrigation is also an issue in this area, as maize cultivation would not be feasible without it due to soil characteristics (rich in stones and gravel, with a low water retention capacity) but the use of sprinklers, here widely diffused to distribute irrigation water, presents some environmental risks: most of the applied water is intercepted by the leaves and flows along the culm, concentrating at the bottom of the plant [17, 31]. In such type of soil, this is a probable cause of deep percolation (water and nitrogen) and decreasing on irrigation and fertilization efficiency; distributing water directly to the soil, under the canopy and along the rows, would reduce this type of losses [9] and therefore the irrigation volumes could be smaller, still allowing sufficient forage productions, important for cattle feeding.

An experiment was carried out in order to evaluate the applicability of a innovative technique to distribute cattle slurry during irrigation on maize. The project

aim was a comparison between a conventional management of water and slurry application and a low impact management using a traveler boom for the distribution of slurry (liquid separated) mixed with irrigation water directly on the soil (fertigation management) in order to reduce nitrogen losses by leaching and ammonia volatilization.

2 Materials and methods

The experiment was conducted in a plot located in Altivole (45°45'50"N, 11°57'38"E), in the high alluvial plain of the Veneto region (North-East Italy). The local climate, according to the de Martonne index, is humid to perhumid. It is characterized by an average annual rainfall of 1034 mm, distributed mostly in autumn and spring, and an annual average temperature of 13°C [3, 34, 39]. For the soil characterization, it was sampled in 8 points at 2 depths (0-25 cm and 25-50 cm) using the Bouyoucos method for soil texture, Walkley e Black method for organic matter and Kjeldahl method for total nitrogen. The soil type is Alfic udarents loamy-skeletal, mixed, non acid mesic soils, according to the USDA classification [1].

The experimental plot was divided in two portions: a conventional management area (CM) of 2.4 ha and a fertigation management area (FM) of 0.4 ha. In the CM area, a tank wagon equipped with splash plate for slurry application was used and irrigation was done using a fixed irrigation system (18 x 24 m apart) with 7 mm nozzle sprinklers. The irrigation water was supplied by local Irrigation District (6 l s⁻¹ of discharge, 3 bar of pressure head at the outlet). In FM area was used a traveller boom (25 m in width) placed on wheel trolley and fed from a hose-reel machine; the boom was equipped with drop tubes (19 mm of inner diameter), similar to a LEPA system [19] to apply water under the canopy without leaf interception [16, 17, 21]. This mechanized system was used both for the irrigation and the distribution of the liquid separated portion mixed with irrigation water (fertigation), hanging the boom above ground at 1.5 to 3 meters to pass overhead the plants. Figures 1 and 2 show the photos of the system with the drop tubes (for use with well developed plants) and without drop tubes (for use in the initial stages of plant growth).

In order to carry out the fertigation treatments, the cattle slurry was treated with a press screw separator [14] and the separated liquid was injected after the turbine drive system of the hose-reel machine from the manure tank by means of a booster pump, by mixing the separated liquid with the irrigation water (about 10% of concentration).



Fig.1 and 2: Traveller boom with and without drop tubes to apply water into the soil under the canopy

Unfortunately, the separator used did not give the expected results, due to the excessive quantity of suspended solids (mostly straw and fiber) in the liquid separated portion that blocked the holes of the boom almost immediately. To overcome the problem, a new mechanical separator was installed and successfully used.

In the CM area was applied 305 kg N ha⁻¹: 180 kg N ha⁻¹ by cattle slurry in preplant (15 March), 25 kg N ha⁻¹ (compound fertilizer) at sowing (20 March) and 100 kg N ha⁻¹(urea) after sowing (June). In the FM area was applied 225 kg N ha⁻¹: 25 kg N ha⁻¹ (compound fertilizer) at sowing, and the remaining during two irrigation (20 June and 9 July). In particular, were applied approximately 80 kg N ha⁻¹ with the first fertigation and 120 kg N ha⁻¹ with the second fertigation.

Slurry, separated liquid and fertigation mixture were sampled for verifying the cattle slurry separation quality and the N content; the analysis took place in the ARAV (Regional Association of Breeders) laboratory.

During growing season leaching water samples were periodically taken with lysimeters to measure the content of nitrate nitrogen in percolation water, in order to evaluate the differences between the two thesis. These instruments did not prove to be reliable, possibly because of the characteristics of the soil. As a result, also four water-catching metal plates, specially designed and built at our Agricultural Mechanics Laboratory, were installed about 40 cm below the soil surface to collect leaching water samples (figures 3 and 4); these new tools allowed to collect and analyse samples frequently during the season.

Air was monitored to evaluate the ammonia emission with a “diffuse wind tunnel” specially designed and built at our Agricultural Mechanics Laboratory, similar to device suggested by Lockyer [18], and utilized in other experiments with success [32]. It consists of a Plexiglas tunnel equipped with a fan to maintain air temperature and humidity conditions similar to those outside; the air is sucked in by a pump through a small polyethylene pipe that contains a phial indicating the amount of ammonia in the air. These surveys were carried out when both slurry distribution and fertigation (liquid separated + irrigation water) were taking place in order to compare the effects of the two systems.

In order to compare the data of ammonia emission with the dose of nitrogen distributed, the Van der Waals equation was used. The sucked volumes by each phial and the air pass through the tunnel were determined in order to define the ammonia volume useful to calculate the number of moles. In this way the number of moles was transformed in grams of ammonia lost. The value found was converted in kg ha^{-1} , by multiplying the estimated grams lost for the production of a hectare, and divided the area covered by the tunnel.

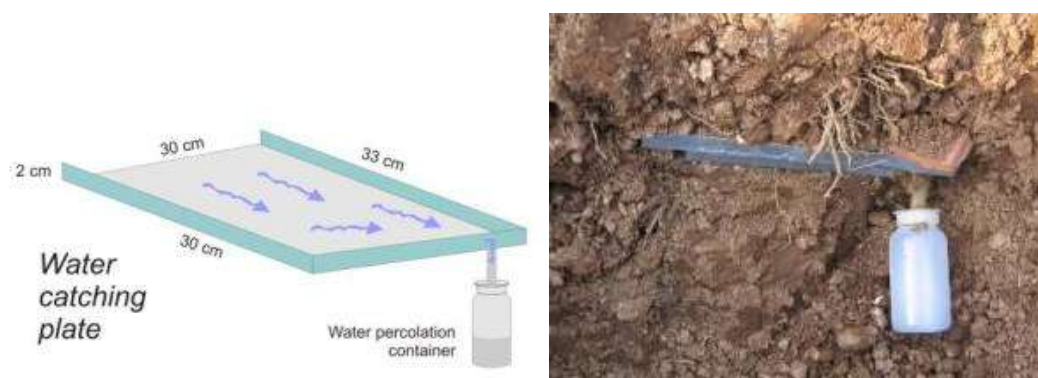


Fig. 3 and 4: The water catching plate installed in the soil

3 Results and discussion

3.1 Slurry analysis

The analysis results of cattle slurry, liquid separated and fertigation mixture are shown in Table 1.

Table 1: Analysis of slurry, separated liquid and fertigation mixture

	Slurry	Separated liquid	Fertigation mixture
Moisture content (%)	91.21	96.59	99.17
N tot (g/100g)	0.71	0.35	0.03
NH ₃ – N (ppm)	4175	2390	193

The analysis showed a good removal of solids in the separated liquid that made possible the execution of fertigation but only after the treatment with the mechanical separator. This problem has delayed the execution of the first fertigation. The analysis of the fertigation mixture allowed to calculate the amount of nitrogen distributed during the two operations of fertigation.

3.2 Quality of leaching water

The four metal plates, installed on an experimental basis, allowed to take samples of percolation water after all the main rainfall and irrigation events. The results of the analysis, even if partial, showed the presence of a higher content of nitrates in water percolation at the beginning of the season and the presence of very high concentration peaks only in a survey point located in the traditional managed portion of the field. In the remaining part of the season the average values were below 35 mg/L in all the points. This leads to identify the initial period of spring as critical with regard to the release of nitrogen in groundwater, and the fertilizations in early spring as those with potentially greater impact in the environment.

Precisely, the concentration peaks were found in a point of the CM area on April 14 and May 19, respectively with values of 280 mg/L and 260 mg/L. Note that the slurry distribution was made on March 15 and the peaks are subsequent to rainfall events, which encourage percolation, preceded by a period characterized by warm temperatures, which promote the process of nitrification. In fact, at the first peak it was recorded 70.4 mm of total rainfall occurred between 9 and 14 April, following a dry period with daily temperatures above 20°C. At the second peak detected on May 19 there was a total rainfall of 60 mm between 16 and 19 May preceded by ten dry days with daytime average temperatures above 23°C.

Overall, at the end of the season, the average content of nitrate nitrogen in leaching water of the two survey points of the FM area amounted to 27.1 mg/L, while in the two survey points of the CM area this value was equal to 48.1 mg/L. In figure 5 is reported the trend of the average monthly concentrations of nitrate nitrogen in percolation water of the two thesis compared to the quantities of N applied.

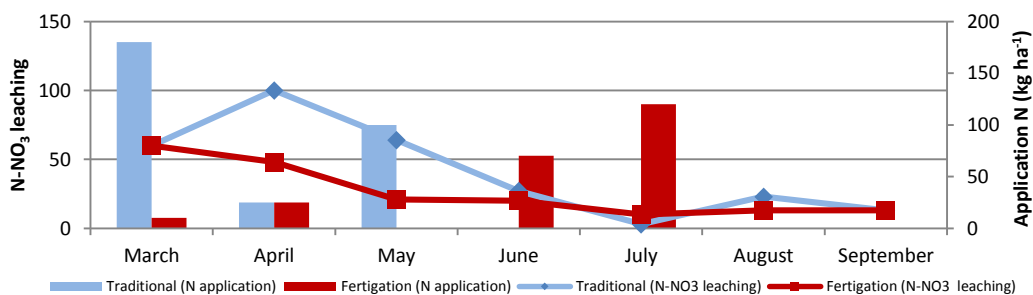


Fig. 5: Average monthly concentrations of nitrate nitrogen (mg/L) in percolation water and quantities of N applied in the two thesis

3.3 Emission of ammonia in the air

As can be seen in the Fig. 6, losses have a logarithmic pattern, indicating that most of the volatilization losses of ammonia occurring in the first hours following

the spreading. These data are consistent with findings in other similar researches [24, 32]. Results indicate that in the first three hours were lost into the atmosphere the 20% of total emission measured in the test with conventional treatment and the 100% of total emission measured in the test with fertigation treatment.

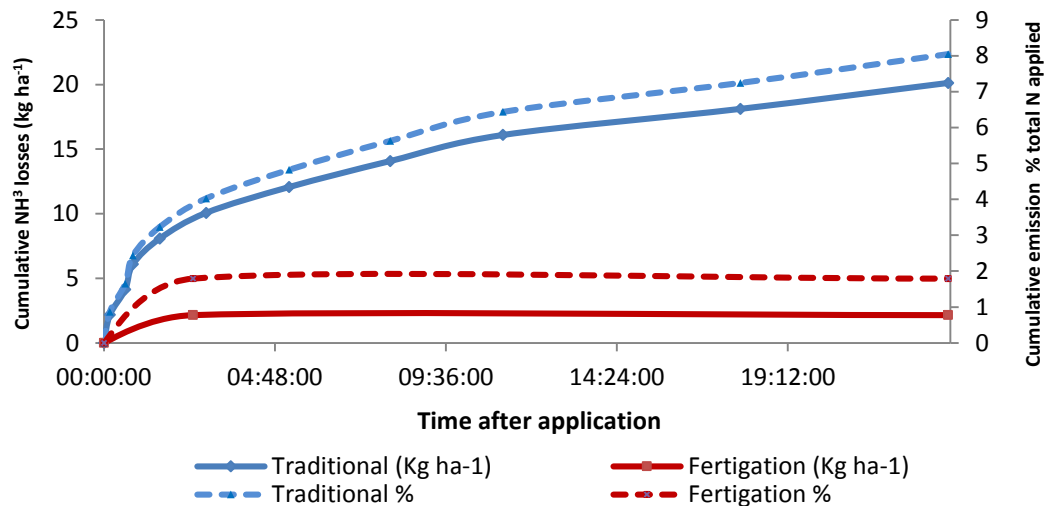


Fig. 6: Cumulative ammonia emission (effective and as % of total N application) in both treatments

In the area treated with the traditional method, in the 24 hours following the slurry application it was detected an ammonia loss of 8% of total nitrogen applied, equivalent to 20 kg ha⁻¹. In the fertigation treatment it was estimated a total loss of 2.15 kg ha⁻¹, corresponding to 1.8% of the total nitrogen applied during the operation; therefore, the percentage of emissions of ammonia is about a quarter compared to the conventional method. This indicates that the alternative system provides a lower loss of ammonia, thus a lower environmental impact and a lower loss of nitrogen useful for plant nutrition.

The reduction of emissions can mainly be associated to the lower content of organic matter of the fertigation mixture than the slurry, which promotes a rapid infiltration into the soil, the absence of the spray characteristic of the spreading of slurry with the splash plate, and the presence of plants in the field to form a barrier.

3.4 Crop Yield

The grain yields of maize are expressed in t ha⁻¹ (considering about 20% of grain moisture) in both years. The grain yields were 14.9 t ha⁻¹ and 12.1 t ha⁻¹ in traditional and fertigation treatments, respectively. In fertigation area the average yield obtained was 18.5% lower than in traditional managed area but with 26% lower nitrogen application, emphasizing a more N use efficiency obtained with this innovative distribution system.

Probably the lower production observed in the fertigation area was due only to the delay in performing the first fertigation treatment (June 20), when the plants had already started the growth stage characterized by a high nitrogen request.

3.5 Comparison among different simulated managements of slurries and fertilizers (doses and times of distribution)

The CropSyst model [33] was used to carry out several simulations by providing different managements of slurry and fertilizers in order to obtain more information on the behavior of the crop, also considering the lack of data collected due to the shortness of the experiment.

Different decennial simulations were set, using weather data available, to allow the model to overcome the initialization phase, and the simulations related to the years 2008 to 2011 were analyzed. In tab. 2 is reported as an example the comparison between the values of grain yield and nitrogen leaching simulated by CropSyst model in the period 2008-2011 assuming the two different managements carried out, with doses of 305 kg N/ha (of which 180 Organic-N in March) in the conventional area and 225 kg N/ha (of which 200 Organic-N in two treatments during June) in the fertigation area.

Table 2: Values of grain yield (20% of grain moisture) and nitrogen leaching simulated by CropSyst assuming the same fertilization doses used in the trial

Management type	Year	Grain yield t/ha	Total N leaching kg/ha	March-May N leaching kg/ha
Conventional	2008	10	143	48
	2009	10	142	48
	2010	11.5	89	28
	2011	11	101	28
Fertigation	2008	10.1	21	8
	2009	10.1	21	8
	2010	11.6	11	4
	2011	11	16	5

Besides, the simulation outputs showed that if farmers renounce to distribute slurry in March and urea or other chemical fertilizer in late May, replacing these operations with a multi-stage distribution of nitrogen (in organic or mineral form) in a period between mid-May and late June, crop productions similar to those obtained with the conventional management could be achieved, but the nitrogen losses by leaching could change significantly. For example, in the period 2008-2010, with fertigation of 170 kg total nitrogen per hectare, as required by the EU Nitrates Directive, divided in three doses distributed between May and June, the CropSyst model estimated that the nitrogen leaching could decrease to only 15 kg N/ha on average, with an average grain yield estimated at 10.5 t ha⁻¹ of dry

matter (equivalent to 13.5 t ha^{-1} at 20% of moisture) that is with an increment on average yield of almost 30% comparing to the values obtained with the same fertilization used in the trial.

4 Conclusions

The proposed irrigation/fertigation system (a traveler boom equipped with drop tubes and fed from a hose-reel machine) can allow the distribution of nitrogen when maize has the greatest needs (vegetative growth and flowering stages); therefore, the doses of fertilizer can be reduced, because at present they are distributed in quantities greater than the real capacity of assimilation of the crop due to leaching losses.

To sum up, as indicated by the field measurements and the results of the simulations performed with the CropSyst model, it can be said that:

1. nitrate nitrogen leaching in the groundwater is mainly linked to the distribution of slurry on bare soil in the rainy season;
2. nitrogen distributions (in mineral or organic forms) when the crop is present in the field do not involve significant leaching problems;
3. the high grain yield is closely related to the content of available nitrogen during the growth period, and particularly between May and June.

In conclusion we can state that the proposed alternative system could help:

- to reduce the quantities of nitrogen distributed to the limits set by the EU Nitrates Directive, while maintaining good maize yields;
- to realize a significant control on concentrations of nitrate nitrogen in groundwater and on ammonia emissions in the air;
- to allow the reduction of irrigation volumes as a result of better water distribution uniformity and efficiency, thanks to the distribution of water directly to the soil, under the canopy and along the rows.

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