

Fertilization Management of Paddy Fields in Piedmont (NW Italy)

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Abstract

A well-documented analysis of fertilization management techniques in use by farmers in a given region is the first step to improving the management standards of agronomic practices. The aim of this work was to summarize the fertilization management that farmers normally utilize for the rice crop in the Piedmont Region of Northwest Italy, and to analyze its agronomic and environmental sustainability. On average, 127 kg ha⁻¹ of N, 67 kg ha⁻¹ of P₂O₅, and 161 kg ha⁻¹ of K₂O were applied to the rice crop. Inorganic fertilizers were used on most of the surface. Calcium cyanamide was the most widely used slow-release product. Commercial organic compounds were spread on about 32% of the paddy surface, while farmyard manure was distributed over 6% of the surface. Organic-mineral products were also widely used. One fourth of the paddy surface received only inorganic products. Using organic or organic-mineral fertilizers together with inorganic products was the most common strategy (55% of the paddy surface). In most cases, N and P fertilization was balanced with crop removal. The N soil surface balance was in the ± 50 kg range for 77% of the surface, P fertilization was less than removal for 53% of the surface, whereas K fertilization was excessive (surplus >100 kg ha⁻¹) for 53% of the surface. The nutrient balance was affected by the widespread practice of burning straw after harvest (66% of the paddy surface). The farmers modulated fertilization according to the rice variety requirements and tolerance to high N supply. The largest nutrient surplus was associated with stocking farms. Inefficient use of fertilizers that should be avoided to improve the territorial nutrient balance were then outlined, and possible specific actions were proposed.

Key-words: fertilization, nutrient balance, rice, water quality.

Introduction

In the last few decades, much progress has been made in the fertilization management of agricultural systems in Italy. Agronomically-oriented research projects have been developed to improve quality standards for surface and ground waters, and to reduce production costs through enhanced fertilization efficiency. However, when moving from the limited and experimental scale to the territorial and actual scale, the reliability of acquired data, the determinism of correlations between variables, and the practical applicability of technical recommendations add uncertainty. Large-scale evaluations of the fertilization impact on water quality are often supported by iterative applications of a simula-

tion model whose inputs consist of field data as variables and locally-calibrated values as parameters. Crop fertilization management is, in all cases, a basic piece of information. Policy makers need large scale evaluations to plan land use, to assess the efficacy of policy measures and the need to introduce new ones, to forecast the effects of a change in policy or in prices, and to discriminate the pollutant load of agriculture from urban or industrial activities. These studies have become urgent in Italy as the need to identify nitrate vulnerable zones (Council Directive 91/676/EEC) in all Italian regions has posed the problem of quantifying not only the amount of nitrogen applied to fields, but also the N surplus, an indicator of the quantity that is prone to transfer to other compartments. Sim-

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ilarly, the water eutrophication problem has stimulated interest in phosphorous derived from cropped soils.

The Water Framework Directive (2000/60/EC) states that protection of water resources can only be achieved through a combined approach of water quality standards and emission limits. Merely reaching a reasonable final concentration of pollutants in water is not sufficient to protect the environment. Rather, agricultural system research should first address pollution source detection originating from agriculture. Both potential sources (nutrient loads due to fertilization) and actual sources (real amounts of pollutants that reach water resources) must be studied so that control measures can be established. Research should then be used to determine the most cost-effective measures that will reduce the impact of agricultural sources for inclusion in the River Basin Management Plan. For instance, precautionary measures could prohibit inefficient fertilization management or impose a threshold nutrient surplus value with indicators calculated on a farm or a river basin scale.

Consequently, the starting point for improving agronomic practice management standards is a well-documented analysis of fertilization management techniques actually practiced by farmers in a given region. Specific territorial survey is the method to acquire such information would be particularly helpful in Italy as official Census and commercial register data cannot be geo-referenced and are not sufficiently detailed for a single crop. Moreover, a survey conducted through direct contact with farmers has the advantage of increasing their awareness of environmental issues, in compliance with the objectives of the Water Framework Directive.

Most scientific studies that are conducted in controlled conditions of research institutes (e.g. Stutterheim et al., 1994; Biloni and Bocchi, 2003) or in semi-controlled conditions of private farms (e.g. Haefele et al., 2003) in order to recommend fertilization techniques to farmers. Some recently published papers have stressed the need to involve farmers and their experiences in defining local fertilization guidelines (e.g. Haefele et al., 2006), or broader issues involving the whole crop management technique (Wassman and Vlek, 2004 stressed the need of a strict cooperation between researchers and

farmers in defining the guidelines to mitigate greenhouse gas emissions). Very few papers instead try to derive information from the actual strategies utilized by farmers. An example of this technique from the Philippines was reported by Fujisaka (1993). Rather than tackling a specific problem, these studies are aimed at collecting basic information for several purposes: (i) to compare the crop management in various environments and pedo-climatic conditions, (ii) to support regional authorities and extension services with useful information to aid their decision-making when defining agro-environmental regulations and territorial development strategies, and (iii) to relate the most common fertilization management techniques with indicators of environmental quality.

This work is part of a wider project aimed at collecting detailed data on the fertilization strategies used for the main crops in the Piedmont plain, and at calculating a nutrient balance at the sub-regional level. This paper is focused on the fertilization technique which is adopted for the rice crop in the Piedmont Region (NW Italy). Its aims were to:

- provide a wide set of data that can be used in territorial modelling;
- describe the normally adopted rice fertilization management in the Piedmont Region “paddy area”;
- analyze the possible reasons for the farmers’ strategies;
- discuss the agronomic feasibility and environmental sustainability of such strategies.

Materials and methods

More than half of the rice-harvested area in Western Europe is in Italy (FAOSTAT data, 2005), and half of this surface is located in a large territory known as the “paddy area” of Piedmont. It is a wide, continuous and unconfined territory located in NW Italy, between 45°00’ and 45°30’ N and 8°10’ and 8°30’ E. The surface of the analyzed territory was 200037 ha. Excluding urban areas, the cultivated land was 174569 ha; of this, 118393 ha were used as paddy fields (ISTAT, 2003).

The agricultural land of the “paddy area” was divided into units which were considered

homogeneous as far as the agronomic aspects were concerned. The land units were characterized through an examination of soil type (IPLA, 1982), irrigation water source (variety of mixed river, lake and canal water), the most diffuse agricultural system, and farm type. Land units were first drawn up on the basis of advisors' personal knowledge, and then corrected (modified in shape, joined or split) when necessary based on the results. Sixty-seven land units with an average surface of 2039 ha were outlined. Representative farms were selected from each land unit depending on their dimensions and inner variabilities. Select farmers were interviewed on their adopted fertilization management technique, the NPK supply (type, amount and splitting), the fate of straw (buried, burned or removed), and the average yield. In total, 105 farmers were interviewed (one per 1700 ha) and 377 cases of fertilization techniques were listed (approximately one per 470 ha). Among these, 298 related to rice and 79 to other crops in the "paddy area". It was presumed that the farmers modulated the fertilization technique according to rice variety, but varieties could not be used to draw the land units because they were not distributed geographically. As about 70 rice varieties were cultivated in the "paddy area", collecting data with the details of each variety was not possible. Therefore, the rice varieties cultivated in Piedmont were divided into seven groups according to their N requirements (influenced by length of the growing cycle and potential yield) and their tolerance to high N supply (height, susceptibility to blast disease and lodging) (Tab. 1). Data were collected in the interview separately for each variety group. Results from the selected farms were extrapolated to the whole land unit through a weight coefficient

which represented the diffusion of each technique over the land unit. The weights represent the extension of a single variety group in each land unit and were derived from the 2000 CAP subsidy database, the most current at the time of the study. The fertilization techniques found in each land unit were then used to calculate a weighted average fertilization input for that same land unit.

The amounts of N, P₂O₅ and K₂O spread through fertilization, those removed with the yield, and their differences (balances) were calculated and weighted over each land unit. The nutrient supply was calculated from the amounts of fertilizers stated by the farmers and the nutrient concentrations in each product. These concentrations were derived from product content labels while data reported by Cortellini and Piccinini (1993) were utilized for farmyard manure (N = 5.0 kg t⁻¹, P₂O₅ = 2.4 kg t⁻¹, K₂O = 7.0 kg t⁻¹). The whole nutrient content of all the fertilizers, including manure, was used in the nutrient balance. The crop removal of nutrients was calculated through the average yield declared by the farmers for each variety group, and an average nutrient content for kernel and straw. The nutrient contents were those reported by Grignani et al. (2003) as an average of the values reported by Fossati et al. (1976), SILPA (1995), Tabaglio and Spallacci (1993), and Grignani et al. (1997). The N concentrations of kernel and straw were 1.35 and 0.80% on a dry matter basis, respectively, while those of P₂O₅ were 0.81 and 0.44%, and those of K₂O were 0.57 and 2.43%, respectively. These concentrations were in general higher than those reported by Witt et al. (1999), Dobermann and White (1999), and in Haefele et al. (2002) for Asian and African environments. In partic-

Table 1. Rice variety groups cultivated in the area: surface expressed as a percent of the total "paddy area", N requirements, tolerance to high N supply, and length of growing cycle. A short duration of the growing cycle makes the variety suitable to the false seeding technique.

Group	Surface %	N requirements	Tolerance to high N	Growing cycle	Main variety
1	27	low	medium	long	Selenio
2	26	high	high	short	Loto, Lido
3	6	low	low	long	S. Andrea
4	11	medium	medium	long	Ariete
5	5	medium	low	long	Arborio, Carnaroli
6	10	very high	high	short	Gladio
7	15	high	high	long	Thaibonnet

ular, the N concentration in grain was approximately 20% greater, while the P and K were 50% greater. The concentrations in straw were about 20% higher for N and K, with negligible difference in P. High concentrations of N, P and K in Italian rice indicates that nutrient pools are available to the crop to a great extent. A harvest index of 0.5 was assumed. Unfortunately, no nutrient content data were available specific to the variety. The soil surface nutrient balance was calculated as the difference between supply and removal at the soil surface (Oenema et al., 2003). It was used as a simple indicator of potential losses (Öborn et al., 2003). Information on fertilization and nutrient balance was geo-referenced and maps were drawn up.

The analysis was conducted during winter and spring 2002; the techniques and yields were those that had been used in 2001. Any variability across the years was not considered in this study.

Irrigation water was generally managed as continuous flooding in the whole study area, with 2-3 short droughts (after seeding to promote rooting, then to spread herbicides and to top dress fertilizers).

Statistical analysis was performed using the analysis of variance to test the effects of 1) variety group and land unit on the management of crop residues (buried, burned or removed); 2) variety group on yield; 3) soil class, water type, rotation/monoculture, animal breeding/not, rice variety group on nutrient supply and balance; and 4) land unit on nutrient supply and balance. All factors were considered as fixed. Interactions were included in the error because they are meaningless in practice. Post-hoc tests were performed using the Duncan method. Any differences between the groups were examined at the 0.05 significance level.

Definitions

The definition of fertilizers may differ from country to country. A brief list of terms used in the text is reported here (all the types of fertilizers are mutually exclusive):

- inorganic fertilizer: a commercial product containing at least one of three primary nutrients: N, P or K. All other nutrients are disregarded;
- organic fertilizer: a commercial product that is derived from animal or vegetable matter, including those containing manure;

- manure: farmyard manure;
- organic-mineral fertilizer: a commercial product that results from a mixture or combination of mineral (inorganic) and organic fertilizers;
- slow-release N fertilizer: a fertilizer that releases nitrogen over a period of time because of low solubility, because it contains bacteriostatical components, or because it is recalcitrant to microbe attacks. P and K may also be present, but their release time was of no importance in this study;
- calcium cyanamide: inorganic product with a slow release effect. This was considered separately from the others, due to its importance in rice fertilization in Italy.

Results and discussion

Nutrient spreading: totals and splitting

A great variety of commercial products were utilized for rice fertilization throughout the “paddy area”: 11 inorganic products with one of the three primary nutrients, 17 inorganic products with two primary nutrients, 16 inorganic products with all three primary nutrients, 15 commercial organic products, farmyard manure, 10 organic-mineral products, 4 slow-release N fertilizers, and calcium cyanamide.

The amount of nutrients spread on the fields using different types of fertilizers are reported in Table 2. On average, a total of 127 kg ha⁻¹ of nitrogen was spread on the rice crop. However, the variability of this value was remarkable as Figure 1a shows. Extreme N applications (exceeding 200 kg ha⁻¹) were always associated with stocking farms. The N fertilizer application times, before sowing or as top dressing, were also quite variable (Tab. 2 and Fig. 2a). Generally, a greater amount of N was applied as top dressing than at sowing. Top dressing was generally split into two applications; one at the tillering growth stage, and the other at panicle differentiation. The percentage of fertilizer spread before sowing had no relation to the total amount spread. The variability in N fertilization and partitioning between sowing time and top dressing reflects the great variety of commercial products that exist with different release times.

Traditional inorganic fertilizers (mainly urea),

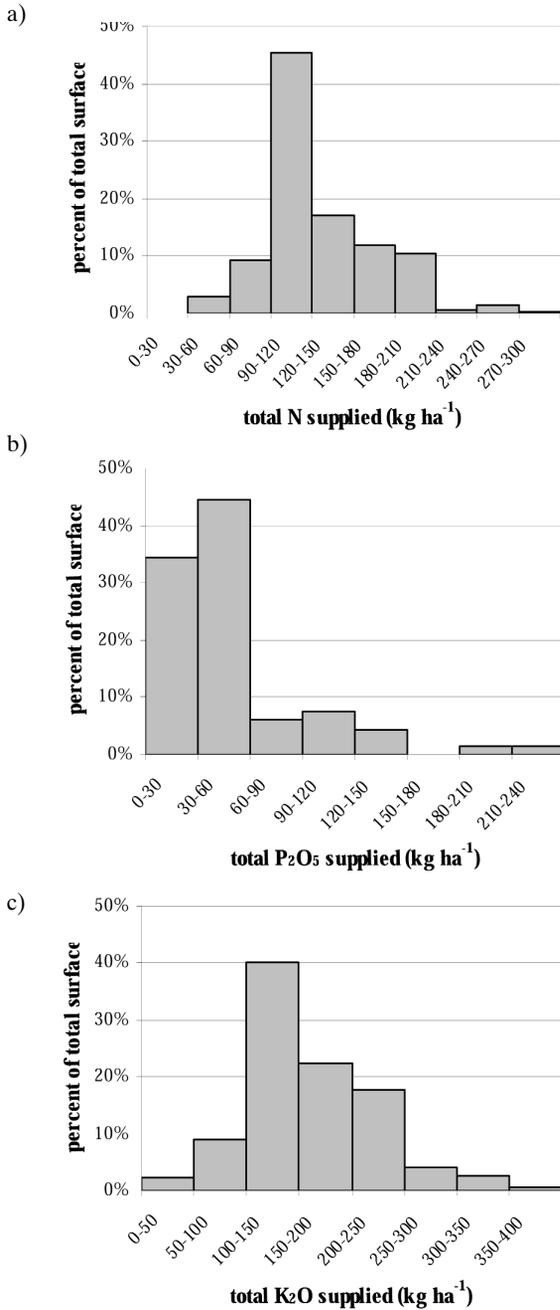


Figure 1. Percent of total surface by the amount of (a) nitrogen, (b) phosphorous as P₂O₅, and (c) potassium as K₂O fertilization that was spread over rice as total fertilization. The mode of total fertilizer supply was: N 90-120 kg ha⁻¹; P₂O₅ 30-60 kg ha⁻¹; K₂O 100-150 kg ha⁻¹.

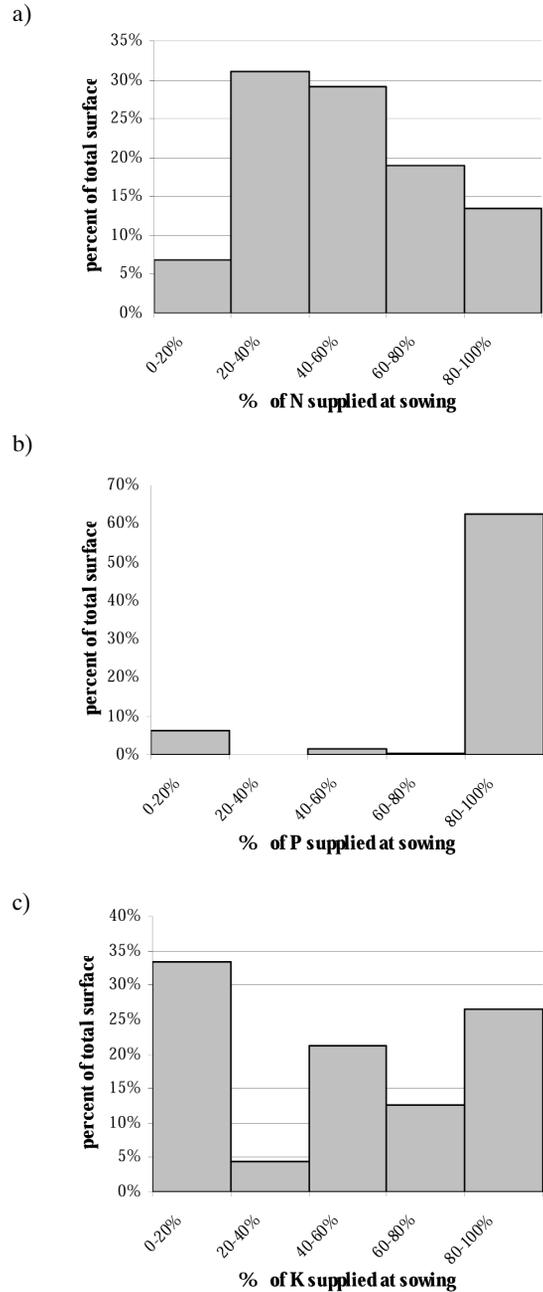


Figure 2. Percent of total surface by the amount of (a) N, (b) P₂O₅ and (c) K₂O spread before sowing, expressed as % of total supply. Most of N and P were top dressed, while K was supplied either as basic fertilization or top dressed.

calcium cyanamide or slow release N fertilizers were used at sowing to apply 55-68 kg ha⁻¹ of N. Among the inorganic products with a slow-release effect, calcium cyanamide was more widely used than recently-developed fertilizers, and,

when used, it supplied about half of the total N. The spreading of calcium cyanamide and methylene urea was limited to sowing time, while coated urea and ammonium sulphate was only spread as top dressing, and some nitrification in-

Table 2. Average amount of nutrients spread on paddy fields through different types of fertilizers, and surface (% of total "paddy area") where fertilizer products were spread. The nutrient amounts only refer to the surface where the specific fertilizer was used; therefore, the "total" column is not the sum of "sowing" and "top dressing".

	Total		Sowing		Top dressing	
	kg ha ⁻¹	% surface	kg ha ⁻¹	% surface	kg ha ⁻¹	% surface
N						
Total	127	100	64	96	73	89
Mineral	98	96	57	53	72	88
Organic	32	34	0	34	0	0
Manure	91	6	91	6	0	0
Organic-mineral	27	29	27	29	0	0
Slow-release	50	7	68	3	34	5
Calcium Cyanamide	55	11	55	11	0	0
P₂O₅						
Total	67	71	66	65	48	10
Mineral	71	46	71	38	48	10
Organic	8	1	0	34	0	0
Manure	44	6	44	6	0	0
Organic-mineral	49	24	49	24	0	0
Slow-release	44	2	44	2	0	0
K₂O						
Total	161	98	133	65	94	77
Mineral	148	95	117	59	94	77
Organic	125	3	0	34	0	0
Manure	128	6	128	6	0	0
Organic-mineral	60	8	60	8	0	0
Slow-release	87	2	87	2	0	0

hibitors were used either at sowing or as top dressing.

Organic compounds were widely used in the rice fields, and generally supplied one-third of the total N. The highest amount of N at sowing was associated with the spreading of farmyard manure, although it was limited to 6% of the total land. Commercial organic and organic-mineral fertilizers were spread at sowing over 34% and 29% of the total surface, respectively, and supplied a relative low amount of N (about 30 kg ha⁻¹). Their wide diffusion indicates that even in the absence of farmyard manure, rice farmers were very interested in using organic materials and prepared to pay for them even though these products are usually characterized by a low nutrient content and a high cost per nutrient unit. Inorganic and slow-release N products were the only sources of N used as top dressing.

On average, a total amount of 67 kg ha⁻¹ of P₂O₅ was supplied to rice, with a wide variability over the surface. Phosphorous fertilizers were widely utilized in the paddy fields, but interviews revealed that 29% of the surface received no P in 2001, indicating that applications were not repeated every year. All of the phos-

phorous was distributed before sowing on 62% of the surface, and as top dressing (approximately one month after sowing) on only 6% of the paddy surface, but seldom at both timings (Fig. 2b). The technical reason for distributing P as top dressing is to reduce the growth of algae when the rice plant is small. Inorganic fertilizers supplied the most P. Other sources were manure, organic-mineral products, and some slow-release N fertilizers containing P.

Potassium fertilizers, on average, supplied 161 kg ha⁻¹ of K₂O. In the majority of cases, K was applied through inorganic compounds. In some exceptional cases, more than 300 kg ha⁻¹ was distributed when KCl was applied (either at sowing or as top dressing) after a distribution of manure. The fertilizer was spread mainly before sowing (> 60% of the total amount) on 27% of the surface, half as basic fertilization and half as top dressing on 21% of the surface, whereas it was spread totally as top dressing on 33% of the surface.

Fertilization strategies

The ways in which different types of fertilizers are combined into a farmer's strategy is report-

Table 3. Combination of fertilizer types used on paddy fields: amount of nutrients (kg ha⁻¹) and diffusion on the paddy surface. The details of N only concern the amount spread at sowing and as top dressing, and the corresponding surfaces are not equivalent to those of the total amount.

Combination of fertilizer types ¹	Surface	N total	P ₂ O ₅ total	K ₂ O total	N sowing	N top dressing
Inorganic only	25%	141	104	157	73	81
Inor + org	55%	119	54	154	48	73
Inor + slow	8%	113	45	183	68	59
Inor + org + slow	5%	110	52	167	88	70
Inor + man	2%	220	84	273	176	44
Inor + man + slow	4%	159	99	212	157	37
No inorganic	1%	113	50	109	80	63

¹ Abbreviations: “inor” = inorganic fertilizers, “org” = organic or organic-mineral (excluding farmyard manure), “man” = farmyard manure, “slow” = slow-release N and calcium cyanamide.

ed in Table 3. One fourth of the paddy surface received only inorganic products. Where this strategy was applied, the amounts of N and P were higher than the overall average values reported in Table 2. One possible explanation with respect to N, is that the farmers thought that higher losses affected inorganic products than organic and slow-release products. A possible explanation for the increase in P fertilization is the low N:P ratio of commercial products, thus confirming that commercial binary compounds may not ensure a reasonable efficiency of both elements. Strategies that excluded the use of inorganic fertilizers (such as in organic farming) were found over only 1% of the surface. The strategy of using inorganic products together with organic or organic-mineral fertilizers was the most widespread (55% of the paddy surface); therefore, the mean amounts of supply were similar to the overall average. Whenever farmyard manure was used, the amount of nutrients that were spread was remarkable: N and K were about 70% greater than the average value, and P increased by about 25%. Farmyard manure was frequently used at high application rates due to the need to dispose of large amounts of excreta as well as the widely held opinion that its efficiency on the crop is low (Grignani and Zavattaro, 1999). N products with a slow-release effect (including calcium cyanamide) were used together with traditional inorganic fertilizers on 8% of the paddy surface. As the efficiency of these products is thought to be high, the amount of distributed N was reduced by about 10%, and this was mainly distributed at sowing.

Management of crop residues

Paddy rice straw in Piedmont is traditionally left on the soil after harvest and then burned, or it

is chopped and ploughed into the soil. The reasons for burning are that farmers fear that i) the decomposition of organic matter in spring could cause toxic effects to the small plants, and ii) partially-decomposed straw could accumulate in the soil and then float during irrigation, due to the low mineralization and humification rates in waterlogged conditions. The practice of straw burning was used widely on over 66% of the paddy surface while it was chopped and buried on 28% of the surface and removed on 6% of the surface. These data vary as a consequence of autumn rainfall; if the autumn is wet, straw is burned on a smaller percentage of land. The analysis of variance showed that the fate of straw was not significantly influenced by the variety group ($P = 0.75$), but was different for the various land units ($P = 0.00$). No clear relationship was found between the management of crop residues and the use of organic or organic-mineral products, thus suggesting that farmers often neglected not only the straw nutrient potential, but also its role as a source of organic carbon to the soil. Those who did not burn straw were simply following legal restrictions concerning air pollution.

Nutrient balance

The N balance was in the ± 50 kg range on 77% of the surface. The surplus exceeded 100 kg on 4% of the surface, and the deficit was never greater than 80 kg ha⁻¹. In most cases, fertilization equalled crop removal. If the whole area is considered, the average excess of N was only 14 kg ha⁻¹. In a soil in equilibrium, this suggests that losses are likely low. The “paddy area” behaves like a whole system where internal imbalances are smoothed through surface water flows,

which connect wide areas through cascade irrigation from one field to another.

Grignani et al. (1997) reported that, as a net balance between irrigation and surface runoff, water supplied 60-130 kg ha⁻¹ of N (at a concentration of 1-11 mg l⁻¹ of total N). Losses as leaching ranged between 90 and 160 kg ha⁻¹. The authors stated that this nitrogen could be re-used as both runoff and shallow drainage contributed to downstream irrigation. In the mentioned paper, the soil surface balance ranged between +50 and +100 kg ha⁻¹ (like 16% of the paddy surface in this study), and the overall balance including leaching and NH₃ volatilization indicated an excess of 50-80 kg ha⁻¹; this surplus was immobilized in the field or lost by denitrification.

The P fertilization was smaller than the removal on 53% of the surface while the P balance exceeded 50 kg ha⁻¹ of P₂O₅ on 11% of the surface. In waterlogged conditions soil P is generally released to the soil solution because of the solubilization of Fe, Al, or Ca compounds, therefore modern rice-growing in Piedmont is apparently depleting soil reserves that were built-up over the previous decades. On the other hand, this also suggests that the present rice management in Piedmont is not contributing to P loads in water courses (Zavattaro et al., 2005).

Potassium fertilization was generally much higher than removal. Specifically, supply was approximately balanced in the ± 50 kg ha⁻¹ range on only 12% of the surface, and the crop was greatly over-fertilized (> 100 kg ha⁻¹) on 53% of the surface. The potassium surplus was not related to the splitting strategy. When straw or straw ashes were not returned to the soil the surplus decreased by 163 kg ha⁻¹. No information could be found on K runoff or leaching from Italian paddy fields, but recent studies in other areas suggest that the losses could be remarkable (Askegaard et al., 2003). Possible reasons for the excessive K supply are: i) soil analyses have indicated a deficit in almost all the fields (Tanaka et al., 1973; Regione Piemonte, 2000); ii) K increases the resistance to lodging and to some diseases (Moletti, 1989); iii) the cost per fertilizer unit is quite low and rice does not suffer from an excess of K. The tables that are used to judge the availability of soil reserves on the basis of chemical tests should probably be revised for the waterlogged soil conditions in

NW Italy. Wihardjaka et al. (1999) and Hu and Wang (2004) reported that non-exchangeable K can be an important source for rice. The latter authors also found that a K application could even cause an annual decrease in the concentration of available K; however, an increase was observed in non-exchangeable K in the tested soil.

Factors that affected fertilization supply and the nutrient balance

Farmers usually modulate the fertilization amount from field to field according to their experience. Not all farmers' choices can be traced back to agronomically sound practices. A balance between crop removal and fertilization could be a valid strategy. Nevertheless, no significant relationship was found in this study between nutrient supply and yield, thus indicating that supply was not modulated to crop removal (which is a function of yield) even when single variety groups were analyzed separately. Figure 3 shows the case of N, as an example. The apparent lack of yield increase from higher fertilization was probably due to the fact that the nutrient supply was in general "high enough" to ensure the maximum yield (Moletti et al., 1992), especially if indigenous N from soil and water is considered as an input. Similar results were also observed in Asian environments by Cassman et al. (1996), Olk et al. (1999) and Dobermann and White (1999), and were attributed to a considerable variability in indigenous nutrient supply and in fertilizer recovery rate. Another possible explanation is that farmers modulated the N supply based not on a mere mass balance, but according to more subtle crop characteristics.

Factors related to (i) the rice variety, (ii) the farm management (stocking farms or not, rotation or monoculture), and (iii) the territory (soil and water types) were tested through an analysis of variance to highlight the possible reasons for the farmers' strategies. The results are shown in Table 4. The N supply was in fact modulated according to the variety group. The nitrogen fertilization amounts agreed with expectations of N requirements and tolerance rather than yield (Tab. 5 and Tab. 1). In stocking farms, the rice crop was supplied with significantly higher rates of nutrients because of the use of farmyard manure: 208, 109 and 284 kg ha⁻¹ of N, P₂O₅ and

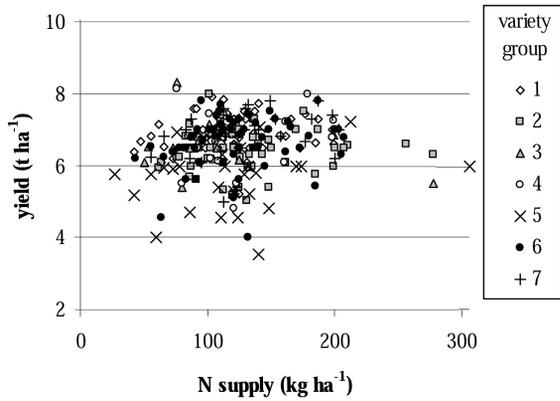


Figure 3. Yield (13% humidity) of the 7 rice variety groups versus total N supply. The yield was not related with the N supply.

K₂O, respectively, were recorded in stocking farms, and 120, 40 and 162 kg ha⁻¹, respectively, in stockless farms. On the contrary, the nutrient supply and balance did not change for monoculture or rotational rice.

Rice was the only crop in the farm on 68% of the surface. When other crops were present, especially in the central part of the “paddy area,” the crops were rotated over the same fields. In the border zones of the “paddy area,” part of the farm was generally devoted to rice production and the other part to other crops. If the use of rotation is expanded within the “paddy area,” an overall increase in N surplus in the area is expected since maize (with a surplus of +112, +19 and +75 kg ha⁻¹ of N, P₂O₅ and K₂O, respectively) is the most likely alternative crop.

The rice fertilization was apparently not modulated according to the local Soil Survey Service classification. This can be explained if we consider that this classification was mainly dependent on the physical traits of the soil, such as depth, texture, or permeability, and that sub-

Table 5. Average yield (13% humidity) and N supplied to the different rice variety groups. The letters indicate a significant difference using the Duncan test.

Group	Yield t ha ⁻¹	N supply kg ha ⁻¹
1	6.88 c	119 ab
2	6.38 b	129 b
3	6.49 b	108 a
4	6.70 bc	125 ab
5	5.87 a	118 ab
6	6.66 bc	123 ab
7	6.86 c	129 b

merged rice is less affected by these features than other crops. The dependence of nutrient supply on the chemical fertility of the soil could not be tested in this work. The water source affected the nutrient supply and balance of all three primary nutrients. A possible reason for this is that farmers have learnt to modulate fertilization according to the water temperature and nutrient content. Irrigation water can, in fact, supply remarkable amounts of N, as previously mentioned (Grignani et al., 1997). Nonetheless, a significant relationship between two variables does not imply a cause effect; other factors might be involved.

Possible improvements of the Piedmont rice cropping system

The analysis of the Piedmont rice agricultural system outlined an inefficient or incoherent use of fertilizers that could be improved through specific measures.

1. The management of crop residues did not seem to reflect the real intention of the farmer to exploit straw as a source of organic carbon for the soil, as the fate of the straw was not related to the widespread use of commercial organic or organic-mineral prod-

Table 4. Values and significance of the F test in the analysis of variance of fertilization amounts and nutrient balance tested using variety group, rotation/monoculture, stocking farms/not, soil class, water type as factors. Symbols: ++ stands for p < 0.01, + stands for p < 0.05.

	Fertilization			Balance		
	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O
Variety group	0.04 +	0.11	0.90	0.41	0.09	0.84
Rotation	0.22	0.10	0.93	0.73	0.18	0.62
Stocking farms	0.00++	0.00++	0.00++	0.00++	0.01+	0.21
Soil	0.20	0.29	0.51	0.23	0.36	0.86
Water	0.00++	0.00++	0.00++	0.00++	0.00++	0.00++

ucts. Farmers should be informed by technical advisors on the advantages of using low-cost sources of organic matter.

2. Although the availability of farmyard manure was very limited in the “paddy area,” it was spread over fields at an excessive rate, thus resulting in a high nutrient surplus. Possible actions could be to improve the farmers’ knowledge and consciousness of the nutrient contents and efficiency of manure, and to promote contracts to transfer manure to other farms.
3. An improper use of special fertilizers was noticed. Farmers made no distinction between organic and organic-mineral products, top-dressed, and some slow-release N products which are only effective in pre-sowing applications when nitrification takes place to a greater extent (Romani, 2003). Specific instructions could lead to an improvement in fertilizer efficiency.
4. Site-specific information on the indigenous pools of nutrients that are available to the farmers was poor, especially as far as N and K were concerned. Setting-up unfertilized plots in a certain number of farms could help to better estimate the real crop requirements.
5. The farmers apparently modulated their fertilizer supply according to the irrigation water quality. Irrigation cooperatives with data on water quality could be involved in setting up areal estimates of the amount of nutrients that are transported by water.
6. A decision support system (DSS) should be developed to help the farmers compile a fertilization management plan that is capable to integrate areal and farm-specific information, to optimize crop requirements and limitations, reduce costs, and also to enforce system sustainability through the prevention of the depletion of soil reserves and water quality.
7. Areas that exerted a greater load of nutrients on water resources were detected through this work. As an example, Figure 4 reports maps of the fertilizer balance. These “hot spots” should be investigated further and control measures implemented according to the urgency identified in the mapping.

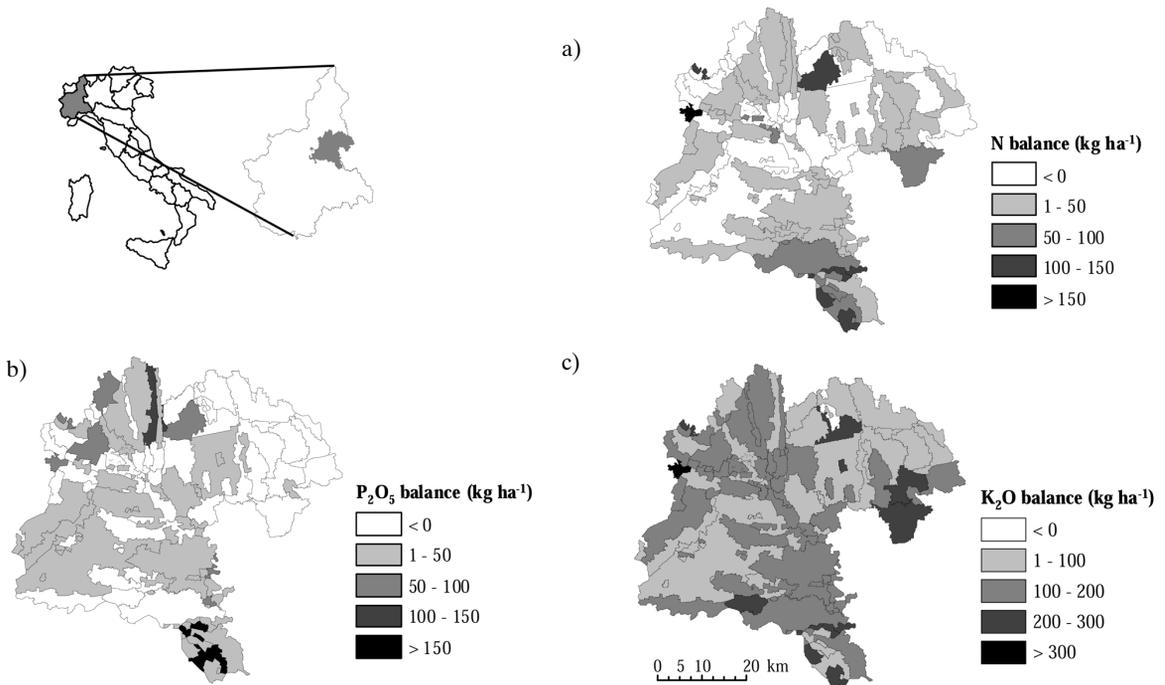


Figure 4. Rice nutrient balance in the 67 land units of the Piedmont “paddy area”; (a) N, (b) P_2O_5 , and (c) K_2O . Data are in $kg\ ha^{-1}$. The N balance was in the 50-100 $kg\ ha^{-1}$ range on 48% of the land surface. The P balance was in the -50-+50 $kg\ ha^{-1}$ range on 80% of the surface. The K balance was in the 0-100 $kg\ ha^{-1}$ range on 42% of the surface, and in the 100-200 $kg\ ha^{-1}$ range on 44% of the land surface.

Conclusions

Sacco et al. (2003) showed that official data sources can be successfully combined and organized in a GIS system to estimate regional nutrient balances. In this study, three information layers were overlaid: official databases, territorial information, and data that was derived from interviews with farmers. These farm-scale information were joined to official sources (Census data and CAP subsidy databases), were referred to territorial units (land units), and were connected to other territorial information (type of soil and source of irrigation water). Following the protocol that has been set out in this survey, periodic updates can be carried out to monitor any variations in farmers' choices over the years due to changing market conditions or European Community policies.

The actual fertilization strategy of a crop is a piece of information that can be used to evaluate and discuss the agronomic feasibility and environmental sustainability of alternative techniques. It also provides basic information that can help to guide research. Regional authorities need this information for land-use planning and to set effective measures for environmental controls. For instance, in Piedmont, both the supply and the calculated balance were used as basic information to identify vulnerable zones for nitrate and phosphorous water quality problems.

The soil surface balance does not include leaching, gaseous losses such as volatilization or denitrification, P adsorption by soil compounds and runoff losses, or extra supplies due to rainfall or irrigation water and eventual symbiotic N-fixation. However, even though no definite judgement can be made on the real environmental load on water sources or on the environment in general, the soil surface balance is a suitable indicator of losses when the lateral movement of nutrients is not important. This occurs in normally cultivated crops or in waterlogged conditions if the study scale is large because the lateral movement is relatively less important in large areas due to the reuse of water.

The soil surface nutrient balance of rice in Piedmont indicated (i) a critical situation as far as K is concerned, owing to an excessive load on the soil and water courses; (ii) a promising reduction of the P supply that should lead to a

general decrease in the P concentration in soils and surface water over the next few years; and (iii) a near-zero overall balance of N, suggesting that the surplus is not as critical as for other crops in Piedmont (maize, in particular). This does not mean that losses are low as the native N did not contribute to the calculated balance. System sustainability can only be achieved if the soil N is preserved through a correct fertilization management plan. The investigation described in this paper provided the starting point for more detailed studies and action plans.

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