NITROGEN FERTILISATION USE EFFICIENCY IN IRRIGATED RICE (*Oryza sativa L.*) UNDER DIFFERENT STRAW MANAGEMENTS

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INTRODUCTION

Rice is one of the world's most important agronomic plants, with 159 Mha under cultivation globally (FAO, 2008). Typically, rice is grown under flooded conditions that result in anoxic soil conditions, throughout a major part of the cropping period. Redox processes in wetland ecosystems play an important role in soil nutrient availability, element cycling, and ecological functions of rice ecosystems (YU et al., 2007). Detailed information on the influence paddy field management practices have on these processes is however, currently lacking or incomplete. Although nitrogen (N) supply drives productivity, poor N fertiliser-use efficiency (FUE-N; 40–60% recovery of applied N) is characteristic of irrigated rice systems (BIRD et al., 2001).

The relationship between fertiliser N uptake and total N uptake by the rice crop over the growing season depends on N fertiliser management and the amount of N available. The latter is the result of a balance of processes, mainly the gross rates of N mineralisation, microbial immobilisation and N losses, affected, in turn by soil properties and agricultural practices such as water and crop residue management. Improved crop and soil management practices are therefore required to avoid excessively low FUE-N, but their development will depend on technologies that can sustain increases in both grain yield and N-use efficiency achieved by rice farmers.

The relatively low FUE-N in lowland rice systems has been largely attributed to a greater degree of immobilisation with respect to upland soils (BIRD et al., 2001) and rapid losses of applied fertiliser-N (CASSMAN et al., 1998). Several field studies have shown that ca. 63% of total N uptake by rice is derived from native soil N and fixed N2, with the remainder derived from fertiliser-N (CASSMAN et al., 1998). In this work, N uptake by irrigated rice subjected to four different water and straw management practices have been compared with the aim of defining best management practices able to enhance FUE-N.

MATERIAL AND METHODS

The experiment was carried out at the long-term experimental platform located in Vercelli, Western Po plain, in the main rice paddy area in Italy. The soil is a Typic Endoaquept, has a loamy texture, low CEC, high available P and low K content, a neutral pH and an average carbon content equal to 10.4 g kg^{-1} soil. In this experiment, four different treatments have been compared. In the first, the soil was ploughed in autumn with contemporary incorporation of the rice crop residues (**AUT**). Successively, the field was flooded and the rice (variety Sirio CL) sown in water at 180 kg seeds ha^{-1} on 28/05/2010. During crop growth two drainages were performed, one for herbicides and fertiliser distribution and one for fertiliser distribution only. The total amount of N distributed was equal to 130 kg N ha^{-1} split over three applications: 60 kg N ha^{-1} in pre-sowing, 40 kg N ha^{-1} at the first drainage (33 days after sowing) and 30 kg N ha^{-1} at the second drainage (52 days after sowing). Successively the field was maintained under flooded conditions until the end of

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August. The rice was harvested on 22/09/2010 when grains reached a moisture content of about 20%. The **SPR** treatment differed from AUT in that the crop residues were incorporated with ploughing in spring, just before flooding. **BUR** was managed similarly to SPR, but the straw was burnt after harvest. Finally the **DRY** treatment differed from all the others as the rice was sown in dry soil at a depth of about 4 cm and flooding delayed by about one month with respect to the other treatments.

In each treatment three different plots (3×3 m) were setup in which different fertilisation techniques were applied: **Control plot** with no N fertilisation to allow for the quantification of N fluxes from crop residues and soil organic matter; **^{14}N plot** fertilised with natural abundance N (as ammonium sulphate), and **^{15}N plot** fertilised with 15N enriched fertiliser (2 atom% ^{15}N ammonium sulphate) to estimate the amount of fertiliser-N taken up by the crop. Experiment was based on a completely randomised design with three replications.

During the growing cycle, biomass sampling was performed at 32, 51, 77, 102, 121 days after sowing. At each time, plants from a 0.5 × 0.5 m quadrants were collected, washed, dried, ground and analyzed for total N and ^{15}N isotope enrichment by high temperature combustion and isotope ratio mass spectroscopy (Flash EA and Delta Plus XP, Thermo Electron). The quantity of fertiliser-N was calculated in each treatment using both ^{15}N dilution as described by Eagle et al. (2001), and difference method corresponding to the difference between N uptake in fertilised plots minus N uptake in non-fertilised plots. The two methods give different results: Isotope dilution directly quantifies the amount of fertiliser-N taken up by the crop and assimilated in the plant tissues. The difference method, instead, attributes the greater amount of N taken up by the crop in fertilised with respect to non-fertilised plots as a consequence of fertilisation. According to Eagle et al., (2001) the difference between the two methods can be defined as Added Nitrogen Interaction (ANI). ANI is caused by immobilisation-mineralisation turnover, in which mineralized unlabeled N replaces fertiliser-N in soil solution (JENKINSON et al., 1985) and is driven by microbial activity.

RESULTS AND DISCUSSION

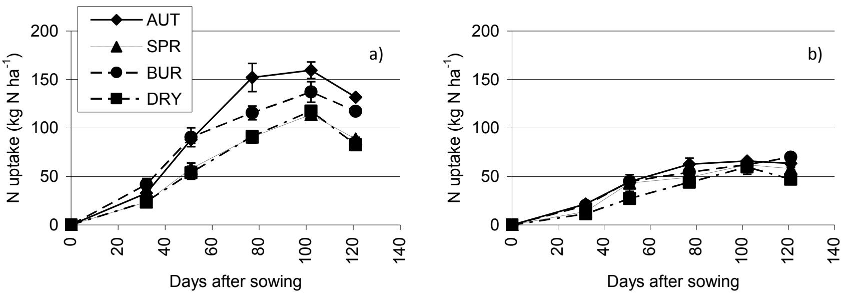

Figure 1: N uptake during growing season in the different treatments. a) Fertilised plots; b) Control plots. Error bars represent standard errors.

The total amount of N taken up by the different fertilised treatments (Figure 1a) was influenced by both total biomass production (BIANCHET et al., 2011) and N availability. AUT and BUR showed greater N uptake than the other two treatments. Moreover, at the last three sampling times, AUT showed greater N uptake than BUR. Both these treatments have a maximum total uptake higher than fertiliser-N supply. The difference between treatments having the greatest and lowest N uptake was about 50-60 kg N ha^{-1}.

In Control plots (Figure 1b) the average N uptake was about half that obtained for fertilised plots. N uptake on these treatments represents the natural N availability derived from decomposition of incorporated fresh crop residues and soil organic matter. AUT showed the highest N availability while DRY showed the lowest.

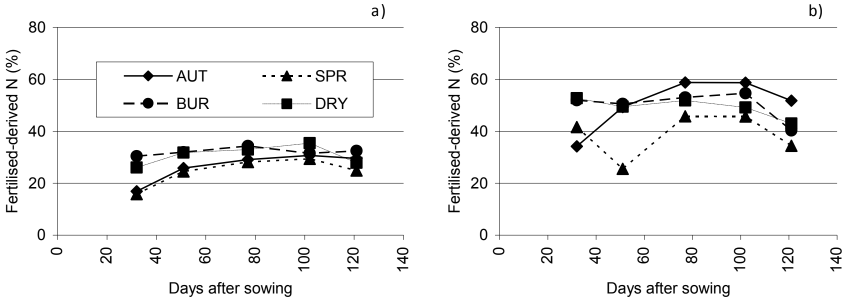

Figure 2: Fraction of total N uptake derived from fertiliser as determined by a) isotope dilution; b) difference method.

The fraction of fertiliser-derived N estimated by isotope dilution (Figure 2a) was generally lower than that calculated by difference method (Figure 2b) indicating that, in agreement with Lin et al. (2004), plants took up more soil-derived N when receiving fertiliser.
Fertiliser-derived ^{15}N was lower in AUT and SPR with respect to the other treatments. However, while the low fertiliser-derived ^{15}N in SPR corresponded to a lower uptake of fertiliser-N, the fertiliser-derived N in AUT (Figure 2b) represented up to 60 % of applied fertiliser, indicating that the incorporation of crop residues in autumn allows for a larger soil N pool available to crops compared to SPR. BUR and DRY showed similar trends and the fertiliser-N uptake is intermediate when compared to the other two treatments. However, they rely on the availability of the fertiliser-N applied.

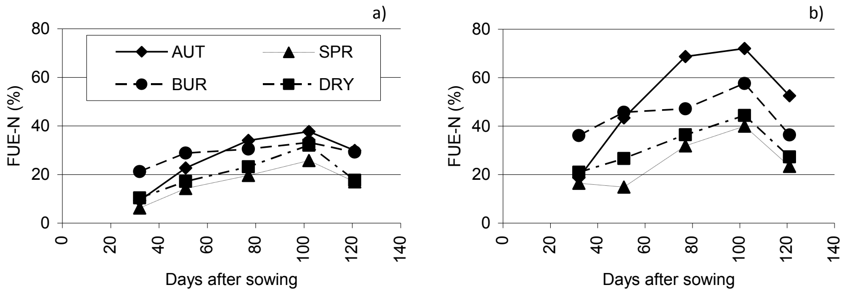

Figure 3: Fertiliser N use efficiency (FUE-N) during growing season determined by a) isotope dilution; b) difference method.

FUE-N, reported in Figure 3, tended to increase over time as a result of the progressive split application of the N fertiliser and for the progressive increase of the plant uptake capacity. The maximum values obtained as average of the different treatment, were 32% by isotope dilution and 54% by the difference method. The FUE-^{14}Ndiff/FUE-^{15}N ratio calculated after 102 days (maximum uptake) showed values ranging between 1.4 (DRY) and 1.9 (AUT). In agreement with Eagle et al. (2001) and Lin et al. (2004), the added nitrogen interaction deriving from fertiliser addition (ANI) is largely affected by water and crop residue management. AUT showed the greatest ANI, suggesting that this treatment resulted in a higher N pool substitution possibly due to a higher soil microbial activity and a more important supply of available N from organic matter decomposition and mineralisation (CUCU et al., 2011). This is also confirmed by the greater N uptake measured in both fertilised and non-fertilised plots. SPR showed the lowest FUE-N values calculated by both methods. This suggests an important immobilisation of fertiliser-N caused by late straw incorporation as well as a relatively low uptake of crop residue-derived N from the mineralisation of freshly added organic matter. In fact it does not show any positive effect on N uptake. In the DRY treatment the N behavior was similar to that observed for SPR. Although the delay in field flooding was expected to favour the aerobic decomposition of the incorporated crop residues resulting in a greater N availability for crop uptake, the results obtained were not substantially improved with respect to SPR treatment. Finally, the BUR treatment that was influenced by a reduced input of fresh organic matter, showed a higher efficiency with respect to the AUT treatment in the early part of the growing season possible due to a low extent of fertiliser-N immobilisation by the soil microbial biomass. However, later in the growing season, the flux of N derived from remobilisation of labile organic matter is lower than that measured in the AUT treatment, leading to a lower maximum efficiency.

CONCLUSION

The aerobic decomposition of crop residues, when incorporated in autumn after harvest, was shown to be essential for increasing N uptake by the rice and FUE-N during the subsequent cropping period. This was facilitated by the faster and more consistent decomposition of the crop residues prior to seeding, thus limiting fertilizer N immobilisation during the growing season. Thus autumn incorporation of straw fosters the capability of soil to supply fertiliser- and soil-derived N to the crop. In cases when rice crop residues cannot be incorporated in the soil in the autumn or winter due to rainfall and/or snow precipitations, burning them will avoid the reduced availability of mineral N and the consequent reduction in crop growth and N uptake resulting from spring incorporation. Dry seeding has not resulted in a greater N availability for crop uptake, as expected.

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