Influence of redox soil conditions and rice straw incorpora on nitrogen availability in temperate paddy soils

Maria Alexandra Cucu[1]; Daniel Said-Pullicino[1]; Luisella Celi[1]

Key words: water management, crop residue incorporation, fertiliser-N, ^{15}N isotope ratio mass spectrometry

INTRODUCTION

Rice is one of the world's most important agronomic plants, with 159 Mha under cultivation globally and is the most important food for more than 50% of the world's population (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).

Nitrogen (N) dynamics in soil–floodwater–rice systems characterised by alternating soil redox conditions, are perhaps one of the most complex biogeochemical systems in agriculture, making it the most yield-limiting and difficult nutrient to manage in rice cropping systems worldwide (EAGLE, et al. 2000). Although N supply drives productivity, poor N fertiliser-use efficiency (40–60% recovery of applied N) is characteristic of irrigated rice systems (BIRD, et al. 2001). The relatively low fertiliser-N use efficiency 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 as a result of processes producing gaseous oxides of nitrogen and N_2, and NH_3 volatilisation (CASSMAN, et al. 1998).

Moreover, the incorporation of crop residues aimed at supplying plant nutrients may strongly influence processes controlling N availability in rice paddies. Mineralisation and immobilisation of N by soil microbes are intimately coupled with organic matter (OM) stabilisation and decomposition, and it is the balance between these two processes that defines the availability of N for plant uptake. In turn, the supply and decomposition of organic materials in rice fields are markedly versatile and are closely related to the crop-residue and flood-water management practices adopted (KIMURA, et al. 2004).

This work aims at providing knowledge on the behaviour of added N fertiliser, N immobilisation and availability as a function of soil redox conditions and rice straw incorporation, essential for developing efficient N management strategies to enhance the synchronization between inorganic N availability and crop N uptake and sustain rice production.

MATERIAL AND METHODS

The influence of soil redox conditions and rice straw incorporation on N dynamics was studied by means of a laboratory incubation experiment. The paddy soil used was collected from a long-term experimentation in Vercelli (NW Italy), and after removal of vegetation and bigger roots, the soil was passed through a 2-mm sieve without drying. The experimental design comprised a completely randomised 2×2 factorial arrangement representing (i) soil incubated under flooded (**F**; submerged under 5 cm of degassed and deionised water) or non-flooded (**NF**; moisture content kept at 50% water holding capacity) conditions, and (ii) with (**S**) or without (**NS**) the addition of rice straw (application dose equivalent to 10 Mg ha^{-1}). Inorganic N was added to the soils at the beginning of the

[1] DiVaPRA – Agricultural Chemistry and Pedology, University of Turin, Via Leonardo da Vinci 44, Grugliasco TO-10095, Italy. (mariaalexandra.cucu@unito.it).

incubation, as enriched ammonium sulphate fertiliser (10 atom% ^{15}N) at an application dose of 56 mg N kg^{-1} soil equivalent to 130 kg N ha^{-1}. A second set of soil samples was treated with natural abundance ammonium sulphate to account for isotope fractionation during incubation.

Incubation was carried out for 160 d at 25°C during which pH and Eh were monitored, and soil samples destructively sampled after 3 hours, 10, 30, 90 and 160 days from the application of fertiliser. NH_4^+ and NO_3^- concentrations in floodwater and K_2SO_4 soil extracts were determined by colorimetric methods, while organic C concentrations were determined by Pt-catalysed, high-temperature combustion (680°C) followed by infrared detection of CO_2 (VarioTOC, Elementar). The amount of immobilised fertiliser-N was calculated from the ^{15}N-atom excess of soil samples determined by isotope ratio mass spectrometry (Delta Plus XP, Thermo Electron).

RESULTS AND DISCUSSION

NF samples showed relatively constant and positive Eh values (mean Eh = 511 ± 6 mV) throughout the incubation period typical of oxic soil conditions, while Eh values of F samples tended to decrease with incubation time (**Fig. 1**). Lower Eh values were obtained for F_S samples with respect to F_NS (minimum Eh = –180 and +9 mV, respectively) suggesting that the addition of labile OM results in a faster consumption of electron acceptors. However, after 60 d, both F_S and F_NS showed similar Eh values. pH values of NF samples were rather constant (mean pH = 5.0 ± 0.1), while pH of F samples tended to increase to around pH 7 over the incubation period, probably due to the consumption of protons when NO_3^-, Fe^{3+} and other species are used as electron acceptors for oxidising OM.

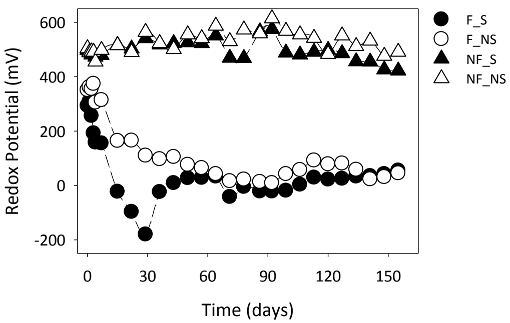

Fig. 1: Variation in soil redox potential with incubation time.

Under NF conditions, the added NH_4^+ was rapidly nitrified within the first 30 d of incubation resulting in a significant increase in soil NO_3^- concentrations. However, NF_S showed lower NO_3^- concentrations with respect to NF_NS for most of the incubation period (**Fig. 2**). On the other hand, under submerged conditions, all NO_3^- originally present in the soil was rapidly denitrified, while NH_4^+ concentrations tended to increase for F_S and decrease for F_NS with incubation time.

To better understand the dynamics of inorganic forms of N, the net N supply was calculated by subtracting the total amount of inorganic N present at t = 0 (fertiliser N + inorganic soil N) from that at time t (**Fig. 3**). A positive net N supply indicates a net mineralisation (from rice straw and/or soil OM), while negative values indicate a net immobilisation (biotic or abiotic), assuming that N losses resulting from NH_3 volatilisation and nitrification/denitrification are negligible.

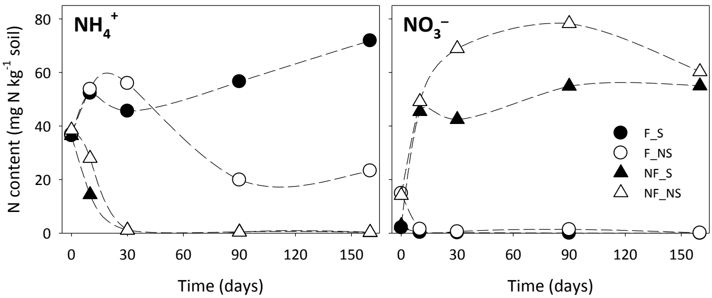

Fig. 2: Changes in inorganic N concentrations with incubation time.
(Values for flooded samples represent the sum of floodwater and soil extract N contents).

Under non-flooded conditions, the addition of rice straw resulted in a significant immobilisation of inorganic N, probably due to the microbial immobilisation of the added fertiliser N in the presence of straw (C/N = 60), or to abiotic immobilisation processes. With incubation time an increase in net N supply was probably due to OM mineralisation that partially compensated for the immobilisation of N. The NF_NS samples showed a net immobilisation at the beginning of the incubation, but after 10 d of incubation the net N supply was positive indicating a net mineralisation. In contrast, under flooded soil conditions, net N supply was generally always negative for both S and NS samples. During the first 30 d, a greater net immobilisation was observed for F_S samples, while for the rest of the incubation a lower net N supply was obtained for F_NS samples. This suggests that although N supply in flooded soils is hampered with respect to non-flooded soils, incorporation of rice straw may partially compensate for this decrease by contributing to N supply through mineralisation.

In all samples, DOC values tended to decrease in the first 10 d indicating a rapid microbial degradation of labile OM constituents (**Fig. 4**). This is in line with the rapid decrease in redox potential observed for the F_S soils and with the increase in inorganic N concentrations observed in all soil samples in the first 10 d of incubation. However, whereas in NF soils DOC values remained low thereafter throughout the incubation period, F samples showed a constant increase in DOC with incubation after 10 d. This was probably due to the desorption of labile, soluble constituents due to the dissolution of Fe-oxides/hydroxides at low Eh values, also confirmed by the higher DOC values obtained for F_S with respect to F_NS. Mineralisation of released labile constituents could further explain the increase in N supply observed for straw-amended flooded samples with respect to those without straw.

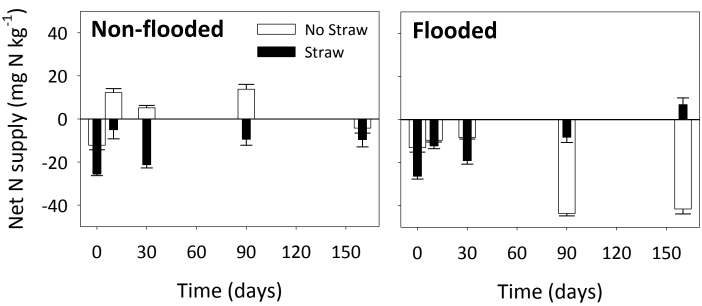

Fig. 3: Changes in net N supply with incubation time.

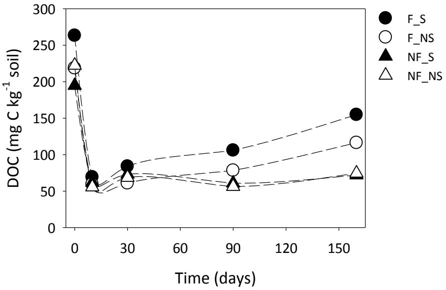

Fig. 4: Changes in DOC concentration with incubation time.
(Values for flooded samples represent the sum of floodwater and soil extract DOC contents).

Stable isotope results showed that by the end of the incubation period the amount of immobilized fertilizer-derived N increased in the order NF_NS < NF_S ≈ F_NS < F_S equivalent to approximately 5, 15 and 50% of the added fertilizer-N respectively. These, results confirm that fertilizer-N immobilization tends to be greater in flooded with respect to non-flooded soils, however the addition of straw strongly influences N availability.

CONCLUSION

Soil flooding generally increased the amount of fertilizer-N immobilized onto the soil after 160 d incubation with respect to non-flooded soils, while the addition of rice straw always enhanced fertilizer-N immobilization. Nonetheless, the addition of straw to flooded soils proved to be essential in increasing N availability within the 160 d incubation period, since the supply of N through OM mineralization greatly compensated for the important immobilization of fertilizer-N.

ACKNOWLEDGMENTS

For the isotope ratio analyses we acknowledge the support of Valter Maurino and Claudio Minero at the Department of Analytical Chemistry of the University of Turin.

REFERENCES

BIRD, et al. Immobilization of fertilizer nitrogen in rice: Effects of straw management practices. **Soil Science Society of America Journal**, v. 65, p. 1143-1152, 2001.

CASSMAN, et al. Opportunities for increased nitrogen-use efficiency from improved resource management in irrigated rice systems. **Field Crops Research**, v. 56, p. 7-39, 1998.

EAGLE, et al. Rice yield and nitrogen utilization efficiency under alternative straw management practices. **Agronomy Journal**, v. 92, p. 1096-1103, 2000.

KIMURA, et al. Carbon cycling in rice field ecosystems in the context of input, decomposition and translocation of organic materials and the fates of their end products (CO_2 and CH_4). **Soil Biology & Biochemistry**, v. 36, p. 1399-1416, 2004.

YU, et al. Major biogeochemical processes in soils - A microcosm incubation from reducing to oxidizing conditions. **Soil Science Society of America Journal**, v. 71, p. 1406-1417, 2007.