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Influence of flooded and dry cultivation methods on rice production and nitrogen mobility in soil and leachates

Authors :

GATTI M.
SASSI D.
SILVA S.
Istituto di Chimica Agraria ed Ambientale, Università Cattolica del Sacro Cuore, via E. Parmense 84, 29100 Piacenza, - ITALIA
Tel : +0523-599369
Fax :+0523-599358

RUSSO S.
Istituto Sperimentale per la Cerealicoltura, S.S. per Torino km. 2.5, 13100 Vercelli, - ITALIA
Tel : +0161-391134
Fax : +0161-294206

Abstract

A lysimeter experiment was carried out on a Vercelli sandy loam soil to evaluate the effects of flooded and dry cultivation methods on rice (Oryza sativa, L.) growth and yield parameters and to determine the fate of applied N fertilizer. Water regimes were continously flooded and irrigated by flushing to mantain 20% of soil moisture. The nitrogen treatments in factorial combination with water regime were 100, 150 and 200 kg urea-N ha^{-1}, each applied in three equal split doses before transplanting, at tillering and panicle initiation. Dry cultivation, compared with flooded condition, significantly increases soil extractable NH_4 and NO_3 which accumulated after the first and second application of N fertilizer. The additional N treatment at panicle initiation was subject to heavy rainfall which saturated soil of dry lysimeters resulting in small soil NO_3 formation. The application of urea before transplanting determines large, rapid losses of NO_3 by leaching expecially in the dry regime. In flooded conditions N loss decreases with increasing crop age, apparently because of the greater demand for NH_4 and NO_3 by rice. Findings on growth and yield parameters were inconsistent with the data of soil N. Whether measured by grain yield response or N uptake, a striking improvement in N uptake occurred under flooded conditions. Nevertheless, total- and protein-N concentrations significantly increased in dry treatments at increasing rates of urea-N application. On an overall basis, this research has demonstrated that reduced yield and N uptake by rice plants in dry conditions could be depending on the larger process of nitrification in the dry soil followed by higher rates of N leaching.

Keywords

- Dry culture, Oryza sativa, L., urea, grain quality, soil N, N loss

Italy

Introduction

Cultural methods for rice (Oryza sativa, L.) production in the world include both flooded and upland with large predominancy of flooded rice culture in temperate areas.

The flood is generally used as a management tool, not a specific requirement of the rice plant. Permanent flooding during the crop growth provides a continuous and adequate supply of water, a better control of nonaquatic weeds, it facilitates the use of granular insecticides and herbicides and it enhances the availability of nutrients such as phosphorus, iron and manganese following reduction of the soil due to the exclusion of oxygen by the flood water (Shapiro, 1958; Ponnamperuma, 1965; Patrick et al., 1985).

However, this system requires large water amounts and may increase the difficulty and cost of applying pesticides and fertilizer and using machinery. Generally, the conventional flooding technique implies a very high water consumption (15,000-20,000 m^3 in the Italian ricefield). Brown et al. (1978) have indicated that 48% of the applied irrigation water was lost through evapotranspiration. The remainder was lost due to runoff and infiltration. Water represents therefore a major and necessary production cost for rice growers. On the other hand, rice producers often have to face increasing competitive uses of water. Moreover, the water quality worsens very often due to the pollution.

With the traditional rice system, under temperate climate (including the Italian), the direct water broadcast sowing method could not prevent some damaging effects of adverse environmental conditions on the plantlets establishment.

The main constraints affecting rice growing under temperate areas at the initial stage are : cold damage, wind effect, crustaceans and worms activity in submerged soil, algae populations development, strong competition of aquatic weeds (such as the Heterathera, spp.) and water shortage.

Alternate methods of planting by drilling and aerobic cultivation (dry rice) are ideal in order to prevent these damaging effects.

De Datta (1975) indicates that rice is grown under upland condition on three continents of the world. Upland cultural system uses only rainfall. Upland production occurs in areas where the rainfall seldom, or never, causes flooded conditions.

Upland yields of more then 7 t ha^{-1} have been recorded, indicating that rice does not require the flood for high yields (De Datta, 1975). To do so, different methods can be used.

Initial researches indicate sprinkler irrigation as an alternate irrigation method. Sprinkler irrigation can contribute substantially to lower water consumption.

An efficient system using sprinkler irrigation in order to prevent plant stress in the critical periods should sustain optimum rice yields. However, reports from several areas have shown highly variable results (Ferguson and Gilmour, 1977 and 1978; Wescott and Vines, 1986; McCauley, 1990). Following these results, further research to compare the effects of normal flood irrigation and sprinkler or other suitable irrigation systems on rice yield and quality is requested.

An alternative method of growing rice like aerobic cultivation is important in order to reduce the cost of rice production and save water. Preliminary studies in Italian climatic environments have shown promising results when rice was grown under a dry cultivation system, using sprinkler or flushing irrigation, indicating that rice does not necessary require flooded conditions for high yield and good grain quality (Losavio at al., 1997; Russo and Nardi, 1996).

Dynamic aspects of nutrient uptake have to be considered in dry condition, with special consideration for nitrogen, in order to optimize the yielding response of rice, as compared to the flooded condition.

In order to develop more efficient rice cultural practices, particularly water and nutrient management, a lysimetric experiment was carried out with flooded and dry rice, with the objective of studing the fate of nitrogen in both soil conditions and the effect on rice yield.

Material and methods

A lysimetric experiment was conducted in 1996 at the Rice Experimental Station, Vercelli, Italy. Bulk soil samples of a

Vercelli sandy loam were collected from the plough layer and packed in the lysimeters. The soil contained 0.12% total N, 2.2% organic matter, 11.5 meq $100g^{-1}$ cation exchange capacity, 0.48% exchangeable K, 0.041% total P and had a pH of 6.8.

Each lysimeter (1.80 m x 0.95 m, 1.7 m^2) was surrounded by polystyrene sheets installed at 50 cm soil depth to reduce thermal excursions. The collection of leachates was ensured by a 30 cm long polyethylene tube placed near the bottom and protruding out of the lysimeter.

The experiment had a factorial design with 4 replications and the following treatments :

- Cultural methods -

Flooded condition maintaining standing floodwater to approximately 5 cm depth and nonflooded condition (dry soil) with periodic irrigations.

- Levels of N -

100 (N1), 150 (N2) and 200 (N3) kg N ha^{-1} as urea applied in three equal split doses. The first N dose was broadcast basically in both cultural methods on dry soil. The second and third doses were topdressed at 4 and 9 weeks after transplanting (WT) at tillering and panicle initiation, respectively.

All treatments received a basal application of 40 kg P ha^{-1} as Thomas sludge and 200 kg K ha^{-1} as KCl.

Rice (Oryza sativa, L.) seedlings were transplanted on May 31 in both cultural methods on dry soil and immediately after lysimeters of the flooded treatments were submerged. The irrigation treatments in nonflooded lysimeters were designed, so that rainfall plus water supply were enough to maintain 20% of the soil moisture. There were three seasonal water treatments.

Soil and leachate samples were removed during the life cycle at 0, 1, 3, 5, 8, 11, 13, 15, 18 and 22 WT and analyses were carried out for NH_4-N and NO_3-N.

Rainfall occurred heavily from mid August to late September and prevented the imposition of water deficit in the dry treatments during this period. Therefore percolation water accumulated in the dry lysimeters and leachates were collected at 1, 11, 13, 15, 18 and 22 WT.

Soil samples were collected from two nylon bags, 120 cm^2 surface areas by 15 cm deep, inserted each at 30 cm long from the shorter side of lysimeters. These soil cores were not transplanted with rice seedlings. During the collection the two soil samples for each lysimeter were thoroughly mixed.

NH_4-N determination in leachates and soil extracts (obtained by shaking 50 g of air-dried soil, < 2 mm, with 100 mL of 0.5M KCl for 30’ in an end-to-end-shaker) was performed by the specific ammonia electrode (Orion).

NO_3-N was analysed by a Dionex Model 2000i/SP ion chromatograph after filtration of leachates and aqueous extracts of soil (obtained by shaking 20 g of air-dried soil, < 2 mm, with 100 mL of distilled water for 60’ in an end-to-end-shaker) through a membrane filter (< 0.2 mm) and a C_{18} cartridge to remove possible organic contaminants.

During the life cycle recorded observations on rice plants included heading date, plant height at different stages and ripening date. Rice was harvested at maturity on October 29 and grain yield was expressed on the 14% moisture basis. An adequate grain sample was taken from each lysimeter to determine head rice yield (milling rate) as a percentage of the whole grain.

Grain was analysed for total N, protein N and NO_3-N contents. Protein N was determined in the residue after precipitation of the true protein with trichloroacetic acid (Licitra et al., 1996). The residue was transferred to Kjeldhal flask and protein N determined likewise total N by the Kjeldhal method. Water extracts of grain were filtered and then analysed for NO_3-N in the same fashion as soil extract.

Analysis of variance was performed to evaluate the variations in yield parameters and in total-, protein-, and NO_3-N uptake due to cultivation methods and levels of N application, as well as the interactions between these variables. A multiple comparison for treatment means by LSD test was performed on the treatment effects at the P<0.05 limit of confidence.

Results and discussion

Total rainfall during the growing season reached 2600 m^3 per hectare. Total water applied (rainfall plus water supply) to dry lysimeters was calculated at 5200 m^3 per hectare. This amount was very low compared with the water applied to a conventional flooded culture consuming about 13-15000 m^3 in this rice area.

Table 1. Effects of water regime and urea-N levels on rice culture.

Soil treatment	Days to ripening (d)	Plant height at harvesting (cm)	Productive tillers (No m^{-2})	Milling rate (%)	Yield (t ha^{-1})
Flooded					
N1	137.0	106.7	850.5	66.5	11.3
N2	138.7	108.5	899.5	65.7	11.3
N3	138.7	109.7	875.0	65.7	11.6
Nonflooded					
N1	142.7	87.9	746.0	66.5	8.23
N2	142.3	78.9	741.5	66.7	7.88
N3	142.2	80.7	769.5	65.7	7.03

Rice growth and yield

Plant height. Changes in plant height as one of the parameters of plant growth are shown in Fig.1. The plant height increased up from the tillering stage to maturity in all treatments. At harvesting time the highest value (109.7 cm) was observed in N3 flood treatment and the lowest (78.9 cm) in N2 dry culture. The difference in plant height was statistically significant between cultivation methods.

When the soil was maintained under continous submersion the plant growth stopped just after the flowering stage. The dry condition appeared to promote the plant growth up till maturity (Fig. 1).

Nonflooded conditions practically had no effect on seedling emergence. Growth and development of rice in dry condition were apparently normal, except for the production of biomass that resulted quite reduced as the data of plant height was lower than in standard culture. In particular, the rice plant showed more reduced and superficial roots due to the inadequate water supply and low moisture content inside the soil.

In flooded lysimeters the increasing of N rate from 100 to 150 and 200 kg ha^{-1} affected generally the plant height. The application of different rates of N in dry conditions resulted in substantially insignificant differences in plant height among the treatments.

Tiller number. The effects of water management on the productive tiller number are shown in Table 1. It should be emphasized that the tiller number per surface unit was slightly reduced in dry treatment compared with the flooded conditions. There were no substantial differences in the productive tiller number among the N treatments in both conditions depending on the water treatment.

Grain yield. Grain yield was significantly lower in dry treatments (7.7 t ha^{-1}) than in flooded condition (11.3 t ha^{-1}). The increase of N rate application did not influence yield in both cultural systems although a tendency for a marginal decrease was seen in dry condition.

Grain quality and N content

Head rice yield. Results of milling process on the grain samples showed that the dry cultivation did not affect negatively the head rice yield (Table 1). On the contrary, the dry soil condition resulted in a slight improvement of commercial grain quality. The maximum value of head rice yield (66.7%) was obtained by the intermediate N treatment in dry lysimeters. This result was very similar to those observed in field experiments with the same water regime.

Table 2. Nitrogen concentration and uptake in rice grain as affected by water regime and urea-N levels.

Soil treatment	N concentration			N uptake		
	Total-N (%)	Protein-N (%)	NO3-N (mg kg-1)	Total-N (kg ha-1)	Protein-N (kg ha-1)	NO3-N (g ha-1)
Flooded						
N1	1.31	1.27	8.61	134.2	130.1	88.2
N2	1.37	1.34	7.17	141.4	137.7	73.7
N3	1.40	1.37	8.66	148.5	145.0	91.8
Nonflooded						
N1	1.50	1.44	6.17	112.8	108.3	46.8
N2	1.57	1.49	5.53	112.1	106.5	39.3
N3	1.59	1.52	4.83	101.9	97.5	31.1

Grain N analysis. Total-, protein- and NO_3-N concentrations and uptakes by rice caryopsis (hulled grain) are shown in Table 2. Total- and protein-N concentrations on dry matter basis were significantly higher in dry treatments than in flooded conditions. Thus as grain yield lowered in dry treatments as total- and protein-N concentrations increased. Application of the higher N rates (N1 and N2) resulted in a significant increase of total- and protein-N concentrations in both cultural methods.

On the contrary, the concentration of grain NO_3-N was significantly higher in the flooded conditions compared with the dry ones, independently of the rate of N application. It seems that the dry condition determined a substantial reduction of NO_3-N accumulation in rice caryopsis with an important gain in rice quality from the point of view of human consumption.

Total-, protein- and NO_3-N uptakes were significantly lower under dry condition than under the flood condition, independently of the rate of N application. It appears very clear that under dry cultivation the N uptake mechanism is dramatically changed and affects the yield. These results could be related in part to the reduced development and activity of the root system.

Soil N

In flooded condition soil NO_3-N remained negligible (<2 mg N k g^{-1}) during all the growth cycle regardless of N levels applied (Fig. 2a). High concentrations of NO_3-N were detectable in dry condition either at 0 or at 5 WT following the first and the second split dose of urea (Fig. 2b). Further on, nitrate increased at 8 WT ranking values from 58 to 88 mg N k g^{-1}, depending on the level of applied urea-N and reaching concentrations very similar to those observed at 0 WT. It seems that nitrification occurred intensively after the second split dose promoting accumulation of soil nitrates.

By comparison, at 11 WT sampling data NO_3-N consistently decreased to less than 10 mg N k g^{-1}. Coinciding with the second top dress application heavy rainfall may have compromised water deficit and the effect of water regime on nitrate dynamic was similar for flooded and dry cultural methods.

Figures 3a and b show an increase of extractable NH_4-N at 5 WT which could be ascribed in both cultural methods to the second split N fertilization. Compared with the flooded treatments, dry condition further enhanced ammonium concentrations at 0 and to some extent at 8 WT. These increasings were also related to increasing levels of N applications. In all the other sampling data, NH_4-N was less than 2 mg N k g^{-1} and remained lower than in flooded conditions.

As per the nitrates, there was no evidence of the third application of urea-N in both cultural methods.

In flooded treatments NH_4-N was always higher than NO_3-N and viceversa under dry condition, with the exception of the sampling at 5 WT when ammonium and nitrate values were about the same.

N loss

Regardless of the levels of N application, more NO_3-N was lost via leaching from the first dose of N applied basically than from the second or third dose (Fig. 4a,b). For flooded conditions this result is well-known since it is supported by other researches (De Datta and Patrick Jr, 1986; Bijay-Singh et al., 1991). Some authors suggest that following transplanting, rice roots exhibited limited ability to absorb and assimilate nutrients (Meelu and Gupta, 1980). Because of that, fertilizer was liable to be lost.

Under flooded soil, following the maximum of N loss at 0 WT, leaching of NO_3-N showed a second delayed peak after which it decreased sharply (Fig. 4a). When comparison between cultural methods was possible, NO_3-N was lost at a higher extent in dry lysimeters.

It is important to emphasize that the soil used in this experiment was light-textured and nitrate leaching may be prevalent in sandy soils.

Leachate NO_3-N was inversely related to soil NO_3-N at different times. After the basal application the concentrations of NO_3-N in the leachate were higher than in the soil, ranging from 11 (at 0 WT) to 3 (at 5 WT) times on the average for the three levels of N applied. This trend was also registered in dry condition at 1 WT (Fig. 4b). Subsequently, leachate concentrations became lower than soil concentrations for both cultural methods.

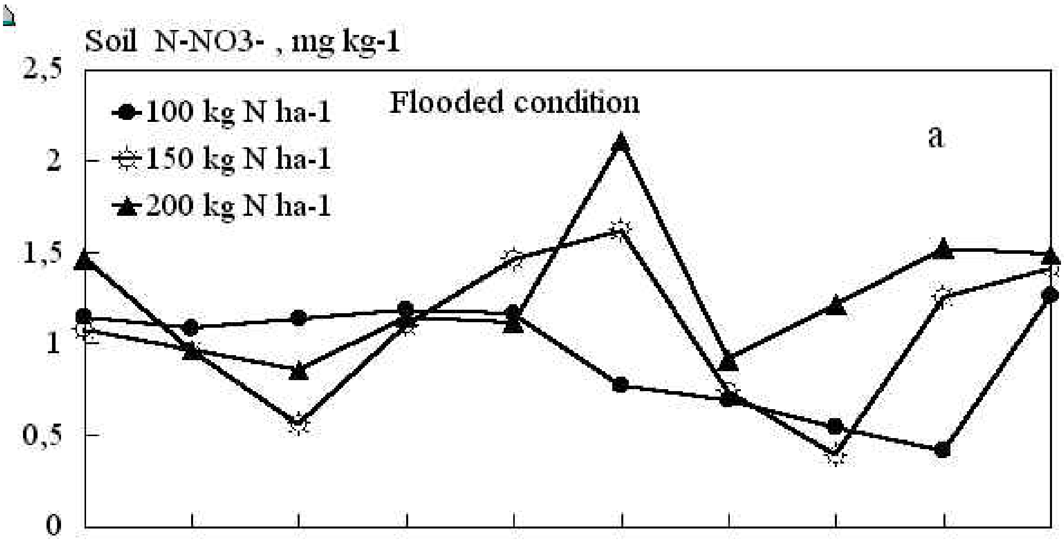
In variance with nitrate, which is mobile in a percolating soil, the tendency of NH_4-N to get adsorbed on soil exchange complex protected ammonium from severe N losses through leaching. Regardless of the cultivation method, ammonium remained low (<1 mg N L^{-1}) in the leachates (Fig. 5a,b), although ammonium can be leached more readily in a reduced than in an arable soil.

Conclusions

Through this lysimeter research, we have demonstrated that the rate of nitrification in dry soil plays an important role in N loss limiting rice root uptake. This was particularly true during the vegetative phase when major losses of N occurred following the basic application of urea. Our studies show that nitrate is the main form of N loss in both cultural methods being ammonium mostly retained in the surface layers. Reduced uptake of N by rice plants in dry condition markedly influenced grain yield and plant height at maturity.

Overall results of this study suggest a potential for rice growth under nonflooded conditions through cultivation practices which allowed a delayed availability of urea-N. Under this situation nitrification inhibitors should be effective in controlling the rate of nitrate formation improving N use efficiency by rice plants. More work is needed, however, on genetic improvement and on a better knowledge of N dynamics in the soil-plant system under nonflooded conditions.

Fig. 1. Changes in plant height affected by water regime and levels of urea-N applied.



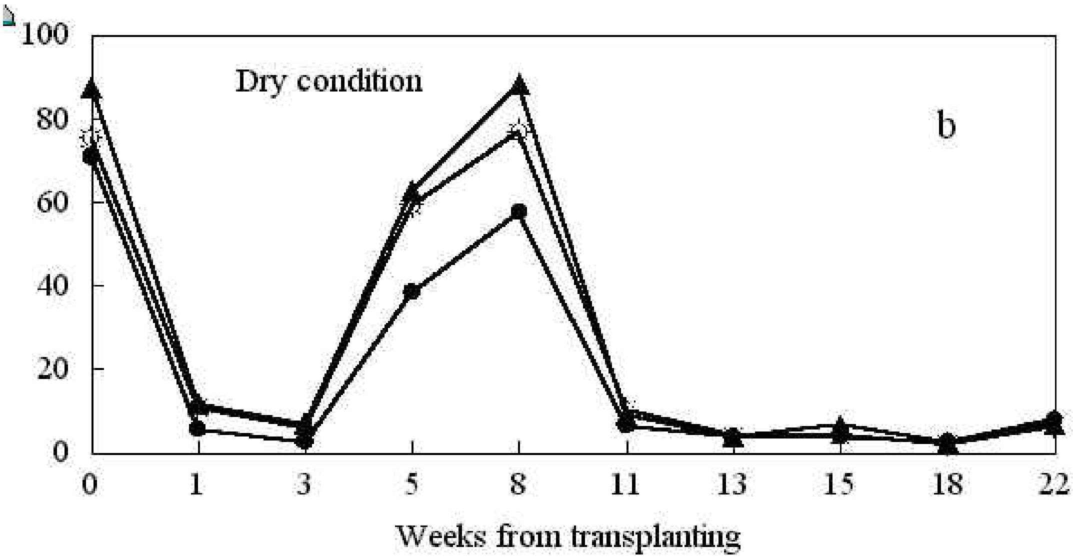
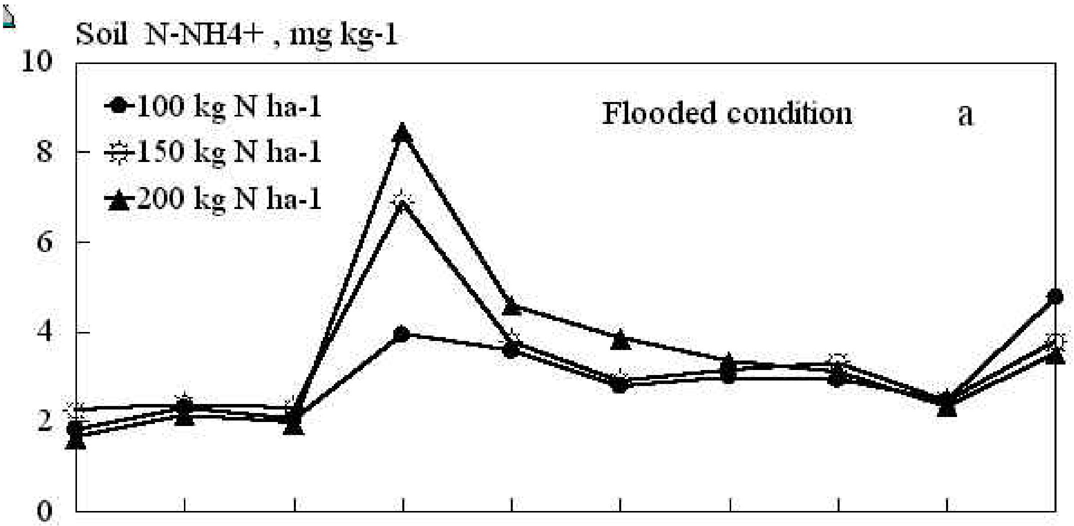


Fig. 2. Effect of flooded and dry cultivation methods and urea-N levels on soil extractable NO_3-N from rice transplanting to harvest.



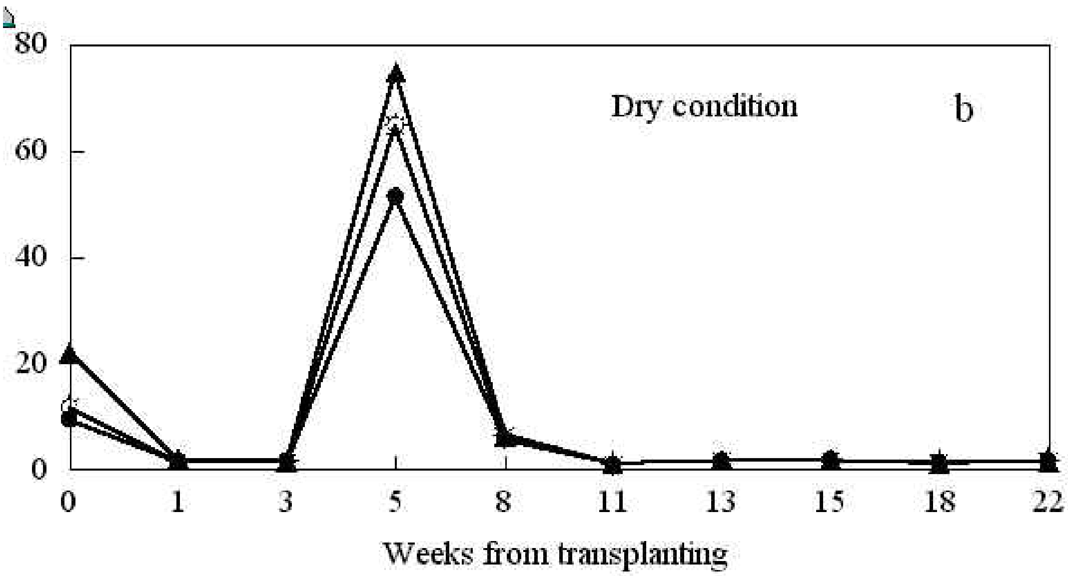


Fig. 3. Effect of flooded and dry cultivation methods and urea-N levels on soil extractable NH_4-N from rice transplanting to harvest.

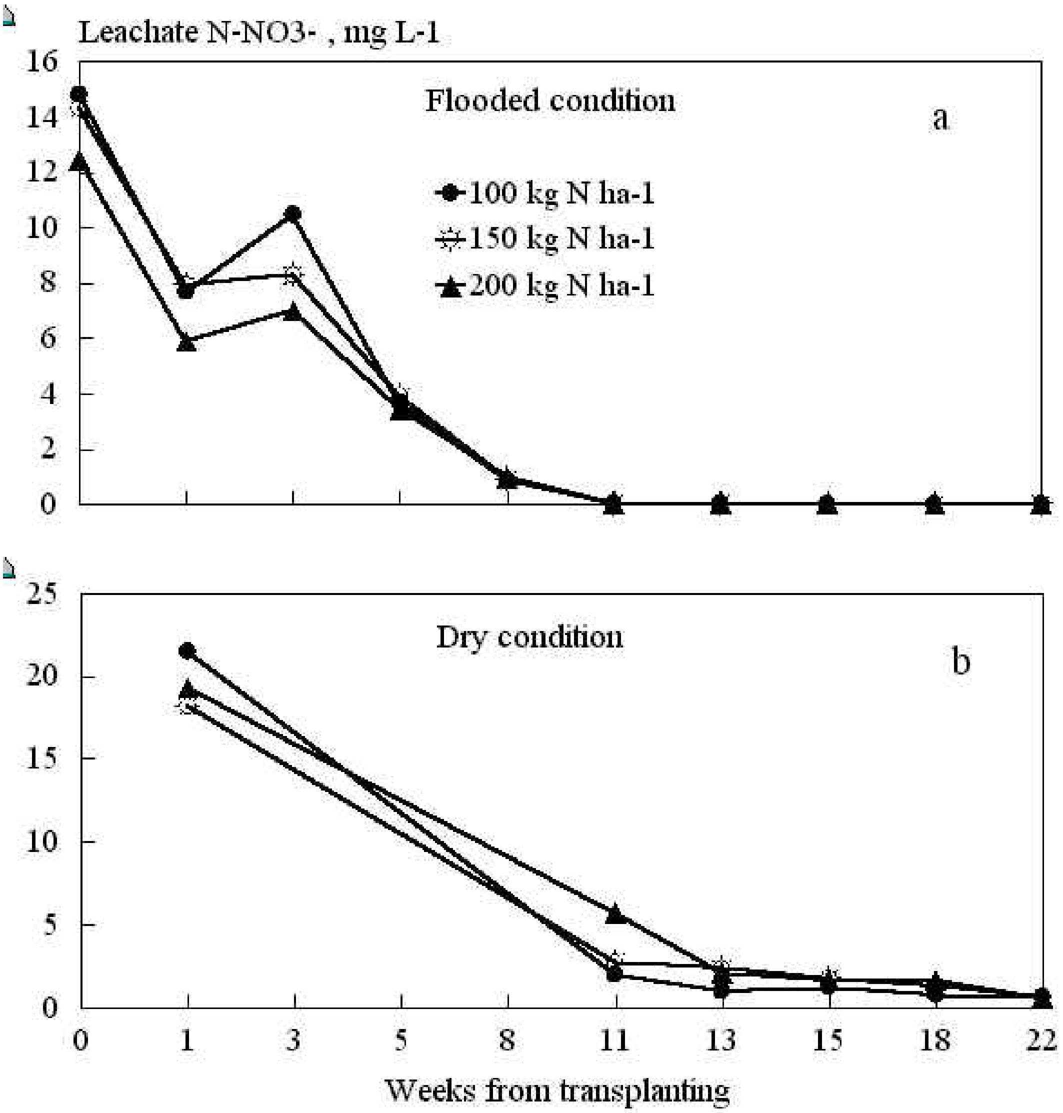
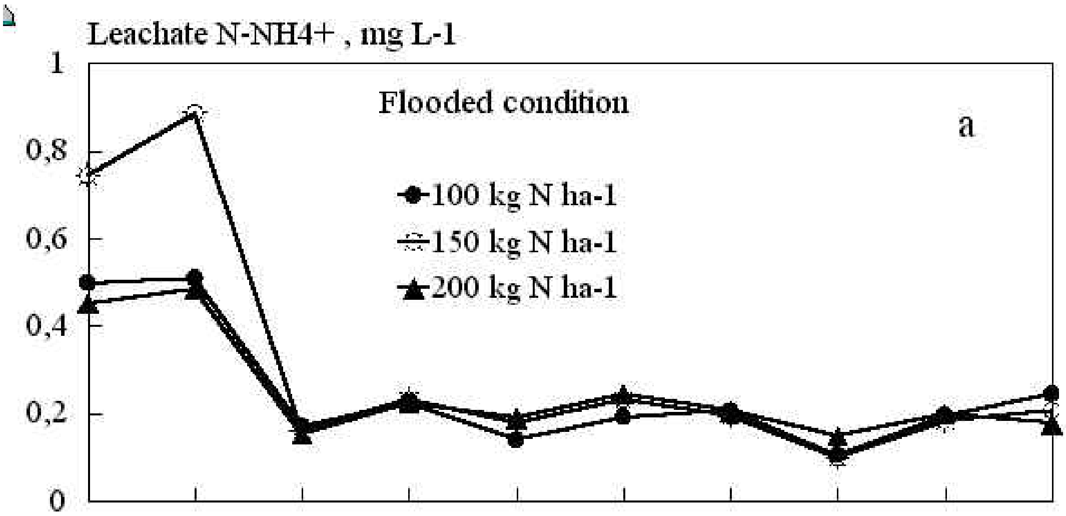


Fig. 4. Effect of flooded and dry cultivation methods and urea-N levels on leaching losses of NO_3-N.



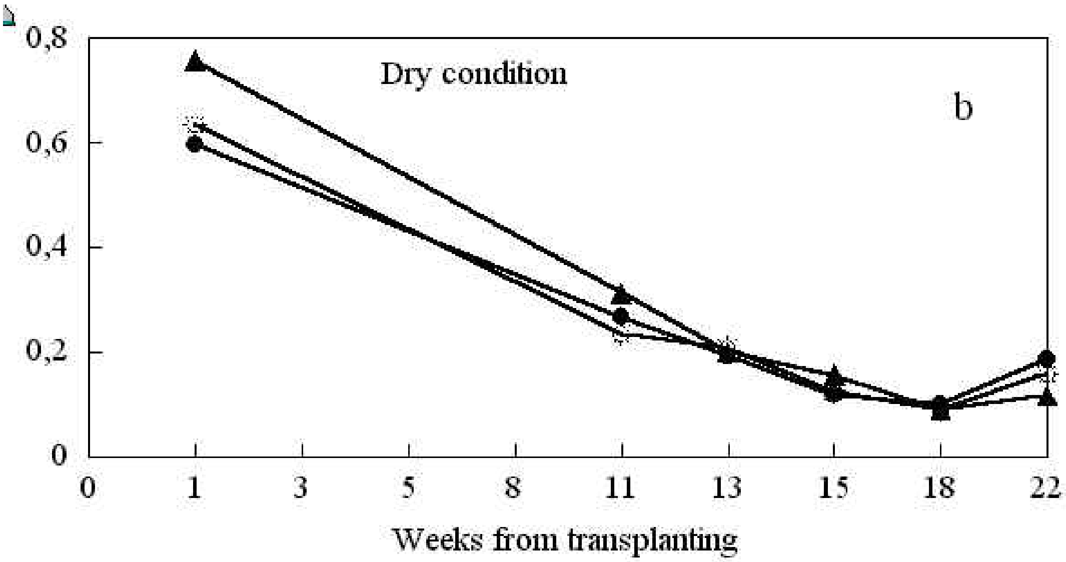
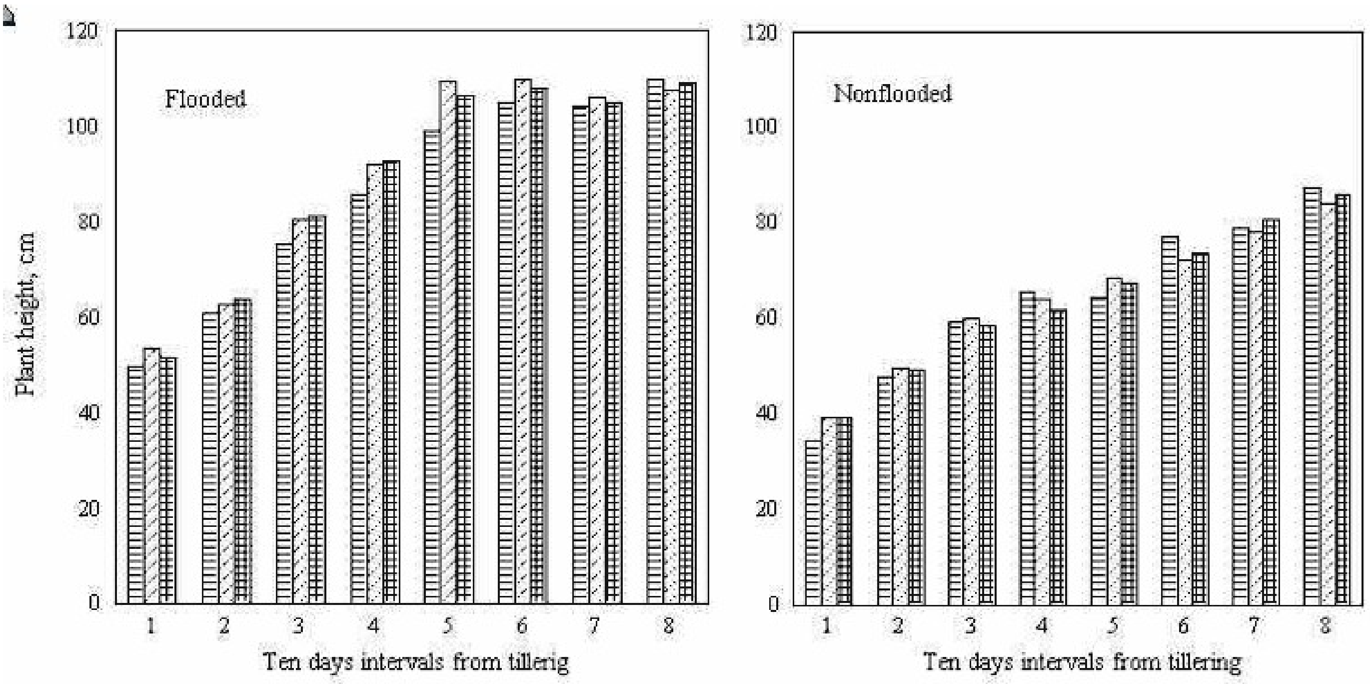


Fig. 5. Effect of flooded and dry cultivation methods and urea-N levels on leaching losses of NH_4--N



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