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ORIGINAL ARTICLE

# Effect of fertilizer deep placement with urea supergranule on nitrogen use efficiency of irrigated rice in Sourou Valley (Burkina Faso)

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**Abstract** The loss of nitrogen (N) can be very high in rice (*Oryza sativa* L.) fields, particularly in the irrigated rice cropping systems with very poor water control. Previous studies have reported very low (30 %) fertilizer N use efficiency by broadcasting in irrigated cropping systems. The effect of fertilizer N (prilled urea—PU) and briquettes—urea supergranules (USG) on rice yield performance and nutrient uptake was investigated in West Africa. Field experiments were carried out in Sourou valley in Burkina Faso in the wet season of 2012 and dry season of 2013. PU was broadcast applied and USG were point-placed deeply into the soil at 5–7 cm using the same fertilizer N rates (52 kg N $ha^{-1}$) and two different rice varieties (FKR 19 and NERICA 62N). The results indicate that Fertilizer Deep Placement (FDP) significantly increased grain yields, particularly in the wet season as compared with broadcasting. The FDP applied to NERICA 62N produced the highest tillers and panicles numbers, leading to more yields. In wet season, FDP significantly increased agronomic efficiency by 39.43 % over PU and physiological efficiency by 24.23 %. In the dry season, differences in the average nitrogen use efficiency (NUE) between FDP and PU were not significant. The studies suggest that FDP is genotype and season-specific, and that it can be used by farmers to improve NUE and increase grain yields in the irrigated rice cropping system. Further investigations are underway to understand seasonal and genetic effect on FDP performance.

**Keywords** Fertilizer deep placement · N uptake · Fertilizer use efficiency · Rice variety

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## Introduction

Nitrogen (N) fertilizer is a major essential plant nutrient and key input for increasing crop yield (Yoseftabar 2013), hence the most yield-limiting nutrient in rice (*Oryza sativa* L.) cropping systems worldwide (Cassman et al. 1998; Ladha and Reddy 2003). It is also predicted that the next generation of humans will continue to depend on reactive N generated in fertilizer factories (Smil 1997).

In Burkina Faso, the production of paddy rice was 226,448 tons in the period 2008–2010 and covered about 40 % of national needs in rice (Kabore et al. 2011). The needs are constantly increasing (825,000 tons in 2015) and this situation requires increased production by improving yields (MAHRH 2010). Currently, the production covers about 60 % of the demand, and 40 % is met from imports. While irrigated lowlands comprise only about 20 % of the total rice area, this system contributes about 50 % to national rice production. Irrigated rice is a production system that can be accessed at high levels of returns, but nitrogen is the main factor limiting yields of these systems (Segda 2006; MAHRH 2003). In Burkina, the average use of mineral fertilizer is about 8 kg $ha^{-1}$ (Bassolé 2007), which is very low.

Today, farmers' practices for nitrogen fertilizer application generally include basal broadcasting without incorporation before transplanting and/or one or two top dressings in the floodwater immediately after transplanting up to flowering (reproductive stage). The efficiency of fertilizer N use is generally low for lowland rice crop as only 30 % of applied N is utilized by crops and the remaining 70 % of it is lost through various processes causing serious environmental problems (Craswell and Vlek 1979; Jiang et al. 2005). The predominant loss process and the amounts lost are influenced by the ecosystem, soil characteristics, cropping procedure, fertilizer techniques, and prevailing weather conditions (Peoples et al. 1995).

Rice is mainly cultivated in irrigated paddy fields, where anaerobic conditions prevail under the top layer (a few cm depth or less) and inorganic nitrogen is maintained as $NH_4^+$ (Freney et al. 1985). The inefficient recoveries of N by plants are caused by nitrate leaching and emissions of $N_2O$ and NOx gaseous from agricultural soil with health and environmental implications (Whitehead 2000). So, proper timing and optimal fertilizer placement can greatly enhance plant uptake of N while reducing environmental contamination. Subsurface placement or incorporated fertilizer is much less subject to surface losses than surface broadcast fertilizer. Thus, the subsurface placement of fertilizer N increase NUE.

In Burkina, mineral fertilizers are directly broadcasted in floodwater. Numerous research reports (e.g. Cassman et al. 1998; Fageria and Baligar 2001) demonstrated that these management practices for application of fertilizer nitrogen in transplanted rice are very inefficient. Crop production systems that optimize yield, reduce N loss and improve N uptake are therefore needed. Nitrogen fertilization positively influences yield (Habtegebrial et al. 2013) as a result of increased tillering capacity, panicle and spikelet number and percentage of filled spikelets (Sathiya and Ramesh 2009).

Rice soils in West Africa show marked responses to fertilizer N; however, judicious use of fertilizer N is a must. In order to meet ever-increasing demand for rice by a growing population, farmers will have to apply modest doses of N fertilizers to increase their yields. The most effective management practice to maximize plant uptake and minimize loss is to synchronize nitrogen supply with plant demand for nitrogen (Peoples et al. 1995). The yield of rice can be improved by optimising the plant's N uptake through increased N recovery efficiency from urea supergranule (USG; Stangel 1989; Savant et al. 1991). Urea Supergranules or urea briquettes are promising materials for West African smallholder farmers because they are large size particles that can be effectively deep placed by hand—fertilizer deep placement (FDP)—in wetland or irrigated rice fields, and can also be locally produced by rice farmers thus increasing their benefits (Bowen et al. 2004; Pasandaran et al. 1999). Fertilizer deep placement with USG is a technology that is now being promoted in Burkina Faso.

This study will provide more understanding of the technology and evaluate genotype and season-specific performance of the FDP technology as compared with the traditional fertilizer application method using broadcast surface application of prilled urea (PU).

**Table 1** Physical and chemical soil properties of experimental site, Sourou Irrigation Scheme, Burkina Faso, 2012

| Property | Wet | Dry |
|---|---|---|
| Sand (%) | 41.4 | 33.00 |
| Loam (%) | 21.8 | 22.30 |
| Clay (%) | 36.8 | 44.70 |
| pH-$H_2O$ | 6.10 | 6.20 |
| pH-KCl | 5.50 | 5.50 |
| Organic carbon (%) | 0.66 | 1.56 |
| Total N (%) | 0.06 | 0.11 |
| Available P (ppm) | 4.00 | 5.60 |
| $Na^+$ (cmol/kg) | 0.23 | 0.24 |
| $K^+$ (cmol/kg) | 0.25 | 0.45 |
| $Ca^{2+}$ (cmol/kg) | 5.50 | 4.90 |
| $Mg^{2+}$ (cmol/kg) | 0.82 | 1.18 |
| CEC (cmol/kg) | 8.60 | 8.70 |

## Materials and methods

### Experimental site

The study was carried out in Sourou Valley in the wet season of 2012 and dry season of 2013. The valley is an intensively cultivated area with a potential irrigated land of about 615,000 ha. The irrigation water is supplied by Sourou River with a capacity of 600,000,000 $m^3$. The geographic coordinates are 13°00'latitude North 03°20′longitude west. The region of Sourou is characterized by a north-Soudanian sahelian climate with an average rainfall below 900 mm. Temperature are stable and between a minimum of 17 °C in coolest season and maximum of 41 °C in hottest season. The soils in Sourou Valley are mainly brown, poorly developed, hydromorphic soils and Vertisols with fine texture, high water retention capacity, low permeability, poor ventilation of sub-surface horizons and strong compaction (Faggi and Mozzi 2000). The soils of the experimental site are slightly acidic; they have a sandy loam texture (Table 1).

### Experimental design

The experiment was laid in a split plot design. The first factor, variety, was randomized on the main plot and the second factor, fertilizer, randomized on the sub-plot. The treatments composing of two improved rice varieties commonly used by rice farmers in the Sourou irrigation scheme (FKR 19 and NERICA 62N) and two forms of fertilizer urea (PU and USG) at the same rate of 52 kg N $ha^{-1}$, were replicated four times. A recommended rate of 69 and 24 kg $K_2O$ $ha^{-1}$ were applied uniformly to all plots except the control at transplanting, as basal in form of triple superphosphate and potassium chloride, respectively. Omission trials conducted at the experimental site indicates that P and K are not limiting rice yield at a certain target yield (data not shown). Thirty days seedlings were transplanted in 20 cm × 20 cm geometry. Each plot had independent drainage and irrigation ditches, so as to prevent the spread of water and fertilizers between plots. The USG was placed deeply into the soil at 5–7 cm between four hills. PU was split in two and was applied at 14 days after transplanting and at panicle initiation. The USG granular was applied in soil at 5–7 cm depth only 7 days after transplanting. Both PU and UDP-plots were regularly irrigated depending on the crop's demand throughout the cropping period.

### Plant sampling and analysis

After harvest, grain and straw samples were collected from each subplot to analyze their total N, P and K contents. The assessment of yield components was made on 1 $m^2$ in each plot.

### Soil sampling and analysis

Soil samples were collected from five points in each plot at 0–20 cm and 20–40 cm depths. The samples were carefully mixed to provide composite sub-sample for the analysis of total N, total and available P, exchangeable K, pH in water, CEC, exchangeable bases, organic C. Total N was determined by Kjeldahl digestion, distillation, and titration and available P was determined by the Bray 1 method.

### Assessment of nitrogen use efficiency

The following parameters were calculated to assess N use efficiency: The Agronomic Efficiency, which is an indicator of the ability of plant to increase grain yield in response to N application and reflects

**Table 2** Interaction effects of combined application of USG and PU on yield and yield components of two varieties of rice, Burkina Faso, wet season of 2012 and dry season of 2013

| Treatment | Grain yield (kg $ha^{-1}$) | Straw yield (kg $ha^{-1}$) | Total dry matter (kg $ha^{-1}$) | Num. of tillers/$m^2$ | Num. of panicles/$m^2$ |
|---|---|---|---|---|---|
| Wet season | | | | | |
| Control | 3,156 | 3,125 | 6,281 | 249 | 177 |
| PU | 4,583 | 4,292 | 8,875 | 239 | 204 |
| USG | 5,146 | 5,139 | 10,694 | 269 | 224 |
| *P* (0.05) | <.001 | <.001 | <.001 | NS | 0.003 |
| LSD | 358.9 | 412.3 | 640.2 | – | 23.36 |
| FKR19 Control | 3,188 | 3,125 | 6,313 | 246 | 189 |
| FKR19 PU | 5,000 | 4,667 | 9,667 | 253 | 212 |
| FKR19 USG | 4,875 | 5,000 | 9,875 | 277 | 218 |
| NERICA 62N Control | 3,125 | 3,125 | 6,250 | 252 | 165 |
| NERICA 62N PU | 4,166 | 3,917 | 8,064 | 225 | 195 |
| NERICA 62N USG | 5,417 | 5,278 | 10,694 | 262 | 230 |
| *P* (0.05) | 0.005 | 0.048 | 0.005 | NS | NS |
| LSD | 454.6 | 914.7 | 877.2 | – | – |
| CV% | 7.7 | 9.0 | 6.9 | 14 | 11 |
| Dry season | | | | | |
| Control | 4,362 | 5,038 | 9,400 | 304 | 301 |
| PU | 6,644 | 5,869 | 12,512 | 326 | 324 |
| USG | 7,000 | 6,375 | 13,375 | 351 | 344 |
| *P* (0.05) | <.001 | NS | <.001 | <.001 | <.001 |
| LSD | 818.8 | – | 1,425.1 | 12.39 | 13.34 |
| FKR19 Control | 4,812 | 4,500 | 9,312 | 318 | 315.8 |
| FKR19 PU | 7,038 | 5,362 | 12,400 | 339 | 340 |
| FKR19 USG | 7,375 | 5,500 | 12,875 | 355 | 347 |
| NERICA 62N Control | 3,912 | 5,575 | 9,488 | 289 | 287 |
| NERICA 62N PU | 6,250 | 6,375 | 12,625 | 312 | 309 |
| NERICA 62N USG | 6,625 | 7,250 | 13,875 | 346 | 342 |
| *P* (0.05) | NS | NS | NS | <.001 | <.001 |
| LSD | – | – | – | 41.66 | 39.10 |
| CV% | 13 | 17 | 11.5 | 4 | 4 |

the overall efficiency of the nitrogen used for dry matter production (Craswell and Godwin 1984).Agronomic N use Efficiency (AE) was determined using the equation:

$$AE = (GYN - GYO)/Nr.$$

Internal Efficiency of a nutrient (IE, kg $kg^{-1}$) is defined as the amount of grain yield in kg $ha^{-1}$ (adjusted to 14 % moisture content) produced per kg plant N, P or K accumulation in above-ground plant DM (oven-dry weight). IE = (GY/Total N uptake) (Witt et al. 1999).

The apparent recovery efficiency of N (ARE) was calculated using the following equation:

$$\%ARE(N) = (UN - U0)/Nr \times 100$$

by Cassman et al. (1996). ARE is the primary index to describe the characteristics of N uptake and utilization in rice.

Physiological efficiency (PE) represents the ability of a plant to transform a given amount of acquired nutrient into economic yield and was calculated using the equation:

$$PE = (GYN - GYO)/(UN - U0)$$

where Nr is the amount of N fertilizer applied (kg N $ha^{-1}$), GY is grain yield, GYN is the N dry grain yield with applied N fertilizer and GYO is the N in the dry grain yield without N fertilizer applied. UN is the plant N accumulation with applied N fertilizer (kg N ha$^{-1}$) and U0 is the plant N accumulation without N fertilizer applied (kg N ha$^{-1}$).

### Statistical and data analysis

The analysis of variance was conducted in accordance with the split plot design using General Linear Model procedure in the SAS package (SAS 1999) to determine the significance of the effects of N fertilization, cropping varieties, seasons and their interactions on yields, N uptake, and NUE parameters. Linear and multiple regressions analysis were used to establish the relationship among grain yield, grain nutrient uptake and nitrogen use efficiency. Treatment means were compared with the *t* test least significant different (LSD) at the probability 0.05. Graphical analyses were done using Excel software.

## Results

### Crop yield and yield components

The yield response to the form and application method of urea varied in the dry and wet seasons (Table 2). The values of yield and yield components were generally higher in the dry season as compared with the wet season. Urea Supergranule significantly increased grain yield as compared with PU in both cropping seasons. Average grain yield obtained was 5,146 kg ha$^{-1}$ in the wet and 7,000 kg ha$^{-1}$dry season. The interaction effect of variety and fertilizer treatments was significant ($P < 0.05$) only in wet season, and USG applied to NERICA 62N gave the highest grain yield (5,417 kg ha$^{-1}$).

The straw yield performance recorded in the wet season using USG was 21 % higher than using PU, and the highest yield performance (5,278 kg ha$^{-1}$) was obtained with NERICA 62N and USG treatment combination. During the dry season the differences in straw yield among treatments were however not significant. But the differences in yield components including number of tillers/m$^2$ and panicles/m$^2$ were significant for all treatments. Thus, tillering capacity and the panicle density were higher using USG than PU, and the variety FKR 19 produced the highest numbers of tillers 355 m$^{-2}$ and panicles 347 m$^{-2}$ (Table 2).

### Plant nitrogen, phosphorus and potassium uptake

In the wet season, rice grain and straw uptake were significantly ($P < 0.05$) affected by urea fertilizer (Table 3). The highest grain N, P and K uptakes obtained using USG were 73.67, 2.71 and 41.01 kg ha$^{-1}$, respectively. The application of USG increased grain N uptake by 3 %, P uptake by 6 % and K uptake by 80 % over PU. There was no interaction between variety and urea fertilizer type for grain N uptake. However, in the wet season, straw N uptakes varied among treatments, and the interaction between the variety FKR19 and PU showed significantly highest N straw uptake as compared with NERICA 62N. Significant interaction ($P < 0.05$) was observed between urea fertilizer type and rice varieties in straw P and K uptakes. And highest P (3.36 kg ha$^{-1}$) and K (50.16 kg ha$^{-1}$) grain uptakes were observed with USG and FKR 19 treatment combination. Urea fertilizer type significantly affected ($P < 0.05$) straw N, P and K uptakes. And highest straw N, P and K uptakes were observed with the control (28.59 kg ha$^{-1}$), PU (0.84 kg ha$^{-1}$) and USG (116.75 kg ha$^{-1}$), respectively (Table 3). The combination of rice varieties and urea fertilizer type significantly ($P < 0.05$) affected straw N and P uptakes, and highest N (41.53 kg ha$^{-1}$) and P (1.21 kg ha$^{-1}$) uptakes were obtained from the combination of FKR 19 and PU treatment.

In the dry season, significant differences ($P < 0.05$) were observed in grain N, P and K uptakes, and highest grain N (106.77 kg ha$^{-1}$) and P 0.98 kg ha$^{-1}$ uptakes were obtained using USG (Table 3). Interactive effect between N fertilizers and rice varieties were significant only for grain P uptake. The combination of NERICA 62N and USG gave the highest increase (15 %) in straw P uptakes, and increases over the control were 81 % for USG and only 27 % for PU. Increases in K uptakes—as compared with control—were 33 % and 20 % using USG or PU, respectively. Greater P and K uptakes were obtained by NERICA 62N using USG (1.09 kg ha$^{-1}$) and by FKR 19 using PU (171.49 kg ha$^{-1}$), respectively.

**Table 3** Effect of urea of fertilizer type on N, P and K uptake in the wet season of 2012 and the dry season of 2013

| Treatments | N Grain (kg $ha^{-1}$) | P | K | N Straw (kg $ha^{-1}$) | P | K |
|---|---|---|---|---|---|---|
| Wet season | | | | | | |
| Control | 45.31 | 1.82 | 10.46 | 28.59 | 0.50 | 10.46 |
| PU | 71.75 | 2.55 | 22.83 | 24.88 | 0.84 | 91.61 |
| USG | 73.67 | 2.71 | 41.01 | 21.61 | 0.46 | 116.75 |
| LSD (5 %) | 5.06 | 0.18 | 1.83 | 2.74 | 0.06 | 16.62 |
| *P* (0.05) | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| FKR19 × Control | 47.81 | 2.20 | 11.73 | 30.00 | 0.66 | 84.41 |
| FKR19 × PU | 76.00 | 3.35 | 26.75 | 41.53 | 1.21 | 119.38 |
| FKR19 × USG | 73.12 | 3.36 | 50.16 | 29.50 | 0.55 | 161.70 |
| NERICA 62N × Control | 42.81 | 1.44 | 9.19 | 27.19 | 0.34 | 98.81 |
| NERICA 62N × PU | 67.50 | 1.75 | 19.92 | 8.23 | 0.47 | 114.13 |
| NERICA 62N × USG | 74.20 | 2.06 | 31.85 | 13.72 | 0.37 | 170.68 |
| LSD (5 %) | 6.48 | 0.22 | 2.42 | 6.64 | 0.15 | 2.42 |
| *P* (0.05) | NS | 0.001 | 0.001 | 0.001 | 0.001 | NS |
| CV% | 7.3 | 6.9 | 6.8 | 10.1 | 9.5 | 6.8 |
| Dry season | | | | | | |
| Control | 72.85 | 1.52 | 27.49 | 49.02 | 0.48 | 126.33 |
| PU | 99.69 | 2.77 | 46.26 | 54.51 | 0.61 | 151.44 |
| USG | 106.77 | 2.98 | 46.03 | 55.46 | 0.87 | 167.78 |
| LSD (5 %) | 14.80 | 0.31 | 5.37 | 9.19 | 0.15 | 28.68 |
| *P* (0.05) | 0.001 | 0.001 | 0.001 | NS | 0.001 | 0.026 |
| FKR19 × Control | 80.37 | 1.64 | 24.78 | 40.05 | 0.45 | 119.92 |
| FKR19 × PU | 95.01 | 2.67 | 46.59 | 46.65 | 0.59 | 171.49 |
| FKR19 × USG | 102.89 | 2.66 | 43.37 | 47.85 | 0.66 | 168.08 |
| NERICA 62N × Control | 65.34 | 1.41 | 30.20 | 57.98 | 0.50 | 132.74 |
| NERICA 62N × PU | 104.38 | 2.88 | 45.94 | 56.74 | 0.64 | 131.39 |
| NERICA 62N × USG | 110.64 | 3.31 | 48.69 | 63.07 | 1.09 | 167.47 |
| LSD (5 %) | 24.46 | 0.51 | 8.51 | 13.88 | 0.19 | 42.40 |
| *P* (0.05) | NS | 0.029 | NS | NS | 0.024 | NS |
| CV% | 14.8 | 11.7 | 12.3 | 16.6 | 20.7 | 17.7 |

## Nitrogen use efficiency

No significant difference was observed in apparent nitrogen recovery (RE). However, interaction effects between rice varieties and urea fertilizer type were significant ($P < 0.05$) (Table 4). In general, ARE-values were higher with FKR 19 than with NERICA 62N, but the latter was more responsive to USG and showed significantly highest increase in RE (57 %). Likewise, the internal N efficiency (IE) significantly ($P < 0.05$) varied among urea fertilizer type and rice varieties only in the wet season. The highest and the lowest nitrogen IE were obtained with USG (54.59 kg $kg^{-1}$) and the control (42.78 kg $kg^{-1}$), respectively. The increase in IE with USG over PU was 12 % in the wet season. USG treatment gave highest IE with the two rice varieties and the best IE was recorded by NERICA 62N using USG (61.58 kg $kg^{-1}$). However, N internal efficiency did not show any significant difference among the treatments in the dry season. In generally, N efficiency-improving effect of USG as compared with PU was observed only in the wet season (Table 4).

The NAE was also significantly related with the grain N uptake ($P < 0.001$) in the wet season. The relationship between NAE and grain N uptake (Fig. 1)

**Table 4** Effect of USG and PU application on N uptake and nitrogen use efficiency of two varieties of rice, Burkina Faso, wet season of 2012 and dry season of 2013

| Treatment | Internal efficiency (kg $kg^{-1}$) | Agronomic efficiency (kg $kg^{-1}$) | Apparent recovery efficiency (%) | Physiological efficiency (kg $kg^{-1}$) |
|---|---|---|---|---|
| Wet season | | | | |
| Control | 42.78 | – | – | – |
| PU | 48.80 | 27.44 | 48.00 | 76.78 |
| USG | 54.59 | 38.26 | 46.00 | 95.62 |
| *P* (0.05) | <.001 | <.001 | NS | 0.04 |
| LSD | 1.81 | 3.8 | – | 17.35 |
| FKR19 Control | 41.07 | – | – | – |
| FKR19 PU | 42.58 | 34.86 | 67.00 | 46.17 |
| FKR19 USG | 47.59 | 32.45 | 48.25 | 69.29 |
| NERICA 62N Control | 44.49 | – | – | – |
| NERICA 62N PU | 55.01 | 20.03 | 28.00 | 107.73 |
| NERICA 62N USG | 61.58 | 44.07 | 44.00 | 121.95 |
| *P* (0.05) | <.001 | <.001 | 0.02 | NS |
| LSD | 3.89 | 23.16 | 22 | – |
| CV% | 3.4 | 9.4 | 23.1 | 16.5 |
| Dry season | | | | |
| Control | 36.19 | – | – | – |
| PU | 41.70 | 43.87 | 57.00 | 51.83 |
| USG | 40.61 | 45.31 | 76.00 | 54.72 |
| *P* (0.05) | NS | NS | NS | NS |
| LSD | – | – | – | – |
| FKR19 Control | 39.58 | – | – | – |
| FKR19 PU | 46.52 | 42.79 | 41.00 | 69.65 |
| FKR19 USG | 44.47 | 38.46 | 55.00 | 53.49 |
| NERICA 62N Control | 32.80 | – | – | – |
| NERICA 62N PU | 36.88 | 44.95 | 73 | 54.02 |
| NERICA 62N USG | 36.76 | 52.16 | 97 | 55.94 |
| *P* (0.05) | NS | NS | NS | NS |
| LSD | – | – | – | – |
| CV% | 19.3 | 40.8 | 63.4 | 22.0 |

was closer with PU ($r^2 = 0.71$) than with USG ($r^2 = 0.59$). In the dry season, the association with the NAE and the grain N uptake was looser for both USG and PU (Fig. 2). There was a positive relationship with the NAE and the total N uptake and 26 % of the variations in grain yield accounted for the total N uptake (Fig. 3). However, the physiological N efficiency was significantly ($P < 0.05$) higher with USG (24.23 %) than PU.

## Discussion

### Yield and yield components

Fertilizer deep placement significantly increased rice grain yield by 12 and 5 % over PU in the wet and dry seasons, respectively. Likewise, straw yield was increased by 20 and 9 % in the wet and the dry season, respectively. Bandaogo (2010) and Yaméogo

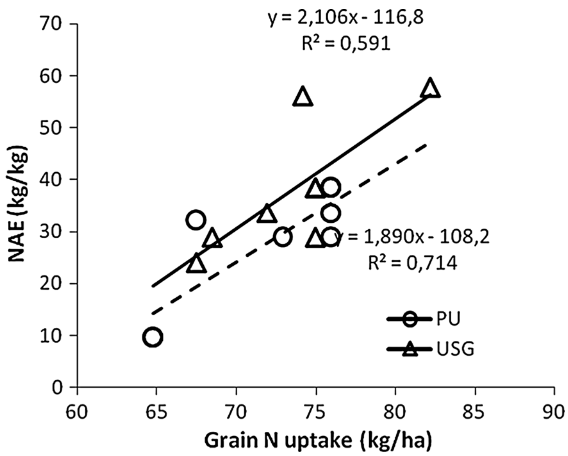


**Fig. 1** Relationship between nitrogen agronomic efficiency and grain N uptake for USG treatment (*triangle*, *full line* and *top equation*) and PU treatment (*circle*, *broken line* and *bottom equation*), Burkina Faso, wet season, 2012

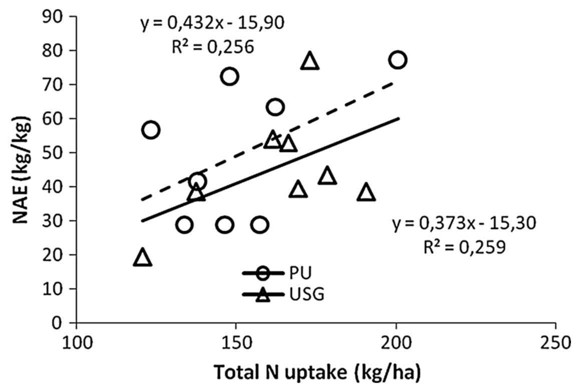


**Fig. 3** Relationship between nitrogen agronomic efficiency and total N uptake in the dry season for USG treatment (*triangle*, *full line* and *bottom equation*) and PU treatment (*circle*, *broken line* and *top equation*). Burkina Faso, dry season, 2013

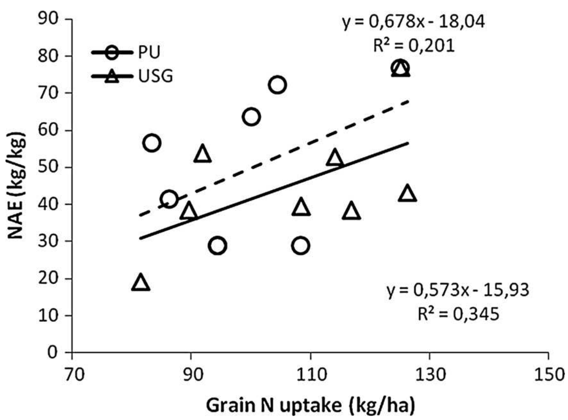


**Fig. 2** Relationship nitrogen agronomic efficiency and grain N uptake in the dry season for USG treatment (*triangle*, *full line* and *bottom equation*) and PU treatment (*circle*, *broken line* and *top equation*), Burkina Faso, dry season, 2013

et al. (2013) clearly indicated that FDP increases grain yield and that increases range between 500 and 1,000 kg ha$^{-1}$. Likewise, many authors including Bowen et al. (2004), Savant and Stangel (1990), Dupuy et al. (1990) and Pasandaran et al. (1999) reported significant yield increases with USG as compared with broadcasting PU. Yield components including number of panicle m$^{-2}$ and number of tillers m$^{-2}$ significantly increased ($P < 0.001$) in the dry season as a result of FDP (Table 2). These differences can be ascribed to the slow release of N from USG over the period of 65 days in synchrony with the plant demand as observed by Gaudin (1988). Apparently, the increase in N uptake positively influences the number of tillers and panicles produced per m$^2$, resulting in yield increase (Yoshida et al. 1972). The multiple regression (Table 5) describing the relationship between grain yield, NUE and grain N uptake in the wet season indicate that grain yield was positively related to all the parameter, but the relationship was significant with grain N uptake only using USG (Eq. 1). Grain yield was significantly ($P < 0.05$) related to grain uptake and PE. However, grain yield is positively related to grain N uptake and decreases with increasing PE when using PU (Eq. 2). These results indicate that grain yield was more associated with N uptake.

The higher grain and straw yields recorded in the dry season could be ascribed to higher solar radiation and temperature which have led to higher photosynthesis performance, compounded with increased mineralization of soil organic matter “priming effect” and hence availability of soil nutrients without any external nutrient inputs. This can be also explained by the higher N, P and K uptakes in the dry season. These results are in accordance with Sheehy and Mitchell (2011) who also recorded higher irrigated rice grain yields in the dry season under irrigation.

**Table 5** Multiple regression of grain yield with NUE parameter and grain N uptake using USG in the wet season

| Wet season | PU | | | USG | | |
|---|---|---|---|---|---|---|
| Parameter | Coefficients | Standard error | *P* value | Coefficients | Standard error | *P* value |
| Constant | 323.713 | 566.475 | 0.608 | −337.588 | 1,106.915 | 0.780 |
| ARE | 100.155 | 97.007 | 0.378 | 386.304 | 614.160 | 0.574 |
| PE | −4.115 | 1.001 | 0.026 | 6.51234 | 2.181 | 0.058 |
| Grain N | 63.075 | 7.463 | 0.003 | 58.667 | 15.783 | 0.034 |
| AE | 0.078 | 2.362 | 0.976 | 9.456 | 7.501 | 0.297 |
| $R^2$ | 0.99 | | | 0.97 | | |
| | <0.001 | | | 0.010 | | |

Y grain yield (USG) = 58.667 (±15.783) grain uptake (Eq. 1)

Y grain yield (PU) = 63.075 (±7.463) grain uptake −4.115 (±1.001) PE (Eq. 2)

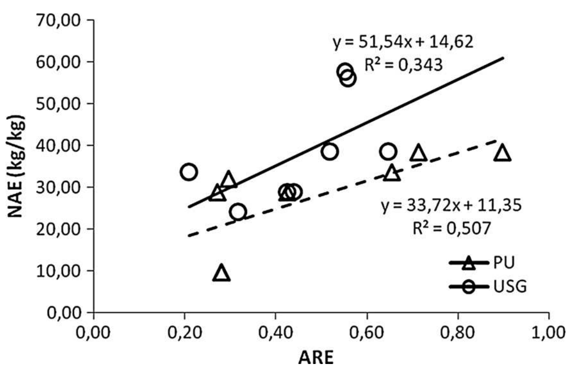


**Fig. 4** Relationship between the nitrogen agronomic efficiency and the apparent recovery of nitrogen for USG treatment (*triangle*, *full line* and *top equation*) and PU treatment (*circle*, *broken line* and *bottom equation*), Burkina Faso, wet season, 2012

## Plant uptake and use efficiency

Average N, P and K uptakes were higher with USG than with broadcasting PU in both, wet and dry seasons. N seems to be the main limiting element for rice yield and its availability may increase the absorption of P and K. Nutrient omissions trials conducted at the experimental site showed that N is the most limiting nutrient (data not shown) as also observed by Dodermann and Fairhurst (2000). Rabat (2003) reported that there is interdependence among plant nutrients. These studies reveal that UDP is effective in increasing fertilizer N use efficiency of irrigated rice as compared to the traditional broadcast application of PU in West Africa. Studies conducted in Asia also invariably showed the superiority of UDP over PU (Hassan et al. 2002; Mohanty et al. 1999). Deep and point placement of urea in anaerobic soil layer limits the concentration of N in floodwater and in the surface oxidized layer, leading to reduced N losses via runoff, ammonia volatilization and denitrification; the final results are increased fertilizer N use efficiency and improved yield gains (Kapoor et al. 2008).

Rice N, P and K uptake and use efficiency varied among the tested rice varieties. The genotypic difference in the rooting system and hence nutrient uptake, and grain filling capacity of FKR 19 and NERICA 62N may vary as nutrient transport to the panicles (translocation) during grain filling is genotype-specific. Many authors reported the influence of genotypic traits such as plant type and growth duration on the nutrient use efficiency (Jiang et al. 2004; Duan et al. 2005; Fageria et al. 2010).

NAE significantly increased with USG application ($P < 0.001$) in the wet season. However the superiority of USG over broadcasting PU was recorded in NERICA 62N plots only. Likewise, nitrogen recovery was genotypic-specific. Sheehy et al. (1998) and Wang et al. (2005) reported that N use efficiency is variable among rice genotypes. NERICA 62N absorbed higher amounts of N, leading to greater yield performance. The result also indicated that NAE and ARE were significantly associated ($P < 0.05$) in the wet season (Fig. 4), suggesting that improving fertilizer N recoveries can also result in increased agronomic efficiency as also reported by Fageria et al. (2010).

## Conclusion

These results clearly suggest that FDP can increase rice grain yield, N uptakes and recoveries which could result in increased revenues for farmer and reduction in pollution as compared to the traditional broadcast application of urea. However, FDP's efficiency is seasonal and genotype-specific. The studies suggest that FDP can be used by farmers to improve nitrogen use efficiency and increase grain yields in the irrigated rice cropping system. It is a promising technology that can be adopted by African farmers, particularly for those rice farmers growing rice in irrigated schemes. However, there is a need for more investigations to understand how seasonal and genetic variability could affect its performance.

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