Response of rain-fed lowland rice varieties to different sources of N fertilizer in Fogera Plain, Northwest Ethiopia

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Abstract: A field experiment was conducted for 2 years during the main cropping seasons of 2017 and 2018 in Fogera Plain to study the productivity response of lowland rice varieties to different sources of nitrogen fertilizer. The experiment was conducted using a factorial arrangement of three sources of N fertilizer (conventional urea, slow-release urea and urea supergranule) and three varieties of rain-fed lowland rice (Hiber, Ediget and X-jigna) laid out in a randomized complete block design (RCBD) with three replications. The recommended rate of 69 kg N ha−1 was used for all three sources of nitrogen fertilizer. Results showed that highest soil-plant analysis development value, leaf area index (LAI), thousand-grain weight, biomass and grain yields of rice were recorded with the interaction of urea supergranule N fertilizer application and Hiber rice variety, while the lowest values of the parameters were recorded with the interaction of conventional urea application and X-jigna rice variety. Rain-fed lowland rice grain yield of 4.6 ton ha−1 was obtained from the interaction of urea supergranule and Hiber rice variety. Economic evaluation results showed also that the highest net return of 58,947.50 Ethiopian Birr ha−1 was estimated from the combination of urea supergranule

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PUBLIC INTEREST STATEMENT

Rice has been becoming the potential food security crop for hundred thousand people in Fogera Plain of Ethiopia. Use of efficient N sources of fertilizers for rainfed lowland rice varieties is not common in the flooded plains of Fogera except the conventional urea. However, poor nutrient management practices are the major ones in rainfed lowland rice production systems. Here, we compared three N fertilizer sources in combination with three lowland rice varieties to improve the productivity of rice crop. However, applications of urea supergranule on lowland rice varieties of Hiber and Ediget is more superior in terms of chlorophyll content, leaf area index, thousand grain weight, grain and biomass yields and net benefits as compared to conventional urea and slow-release urea. Therefore, these technologies should be intensified on a large scale in present and future as a rainfed lowland rice production system in Fogera Plain.
and Hiber rice variety. According to the present results, the interactions of urea supergranule N fertilizer with Hiber and Ediget rice varieties were found as the first and the second outsmarted combinations that would be used further for exploiting more grain yield and net benefits of rain-fed lowland rice without yield penalty in Fogera Plain, northwest Ethiopia.

Subjects: Agriculture & Environmental Sciences; Crop Science; Soil Sciences

Keywords: lowland rice variety; net benefit; N sources; SPAD value; urea supergranule

1. Introduction

Rice (Oryza sativa L.) is one of the most top cereal crops in the world and the staple food for more than half of the world’s population (Ahmad et al., 2009; Buresh, 2015; Fageria, Dos Santos, & Coelho, 2011; Mulugeta, Sentayehu, & Kassahun, 2011). Globally, no food grain is more important than rice from a nutritional, food security or an economic perspective. Considering its composition, rice grain is high-quality food and milled rice grain contains 80% starch, 7.5% protein, 0.5% ash and 12% water (Reddy, 2006). The world average paddy rice productivity is about 4.6 tons ha⁻¹ (FAOSTAT [Food and Agriculture Organization Statistics], 2018). Globally, annual paddy rice production covers an area of 167.2 million hectares with 769.9 million tons of grains. According to FAOSTAT (2018), the production share of paddy rice in the world was 90% in Asia, 5.2% in America, 3.5% in Africa, 0.6% in Europe and 0.1% in Oceania. Rice is one of the important crops that is grown in Fogera Plain of Ethiopia (Tesfaye, Befekadu, & Aklilu, 2005). The national average productivity of rice in Ethiopia is however low about 2.8t ha⁻¹ (CSA [Central Statistical Agency], 2018). This low rice productivity in the country is associated with lack of various N sources of fertilizer and improved rice varieties (Roy & Chan, 2015).

Improved nutrient management practices such as different sources of N fertilizer are not used for rice production in Fogera Plain. Among the different sources of N fertilizers, conventional urea, slow-release urea and urea supergranule (USG) have the potential to increase the productivity of lowland rice (Emran, Krupnik, Kumar, Ali, & Pittelkow, 2019; Fageria, 2009; Mi et al., 2019; Prasad, 2009). These N fertilizer sources with the combination of rice varieties do have variations in tillering capacities, fertile panicles and thousands seed weight (Sarangi et al., 2015; Uphoff, 2003). To aid N management, cropping sensor-based technology such as soil-plant analysis development (SPAD) is one of the best strategies for efficient application of nutrients in the future (Colaco & Bramley, 2018; Teoh, Hassan, Radzali, & Jafni, 2012). Management practices alone will not prevent all nitrogen losses and it may be necessary to use enhanced efficient fertilizers such as controlled release products, urease and nitrification inhibitors to obtain a marked improvement in the efficiency of flooded rice (Chen et al., 2008).

The major limiting nutrient for lowland rice production in Sub-Saharan Africa is nitrogen (Saito et al., 2019). According to Bandaogo (2014), nitrogen uptake of rice crop varies from soil type, water control, pH and water temperature, doses and modes of supply and varieties. The same author indicated also that USG was more efficient than prilled urea (PU) at all levels of nitrogen in producing all yield components and in turn, grain and straw yields (Ahmed, Islam, Kader, & Anwar, 2000; Alee, 2013). According to Mishu (2014) and Rahman et al. (2016), responses of rice varieties to N fertilizer sources revealed that yield and yield components of rice and nitrogen use efficiency significantly increased with application of USG in the form of 1.8 g and 2.7 g pellets.

Using appropriate N fertilizer sources is important for improving N use efficiency of crop plants (Fageria, 2009). Such practice increases not only yield, but it reduces also cost of production and environmental pollution. Urea and ammonium sulfate are the two main nitrogen carriers used worldwide in lowland rice production (Fageria, Dos Santos, & Moraes, 2010). According to Fageria et al. (2010), urea (46% N) is generally favored by the growers over ammonium sulfate (21% N) due to its lower application cost. Mixing fertilizers into soil and injecting them into the subsurface are more efficient
methods of N application compared to broadcasting and/or leaving them on the soil surface (Fageria & Baligar, 2005). The amount of volatilized NH\textsubscript{3} and NH\textsubscript{3} losses would be minimized as N fertilizers are incorporated into the soil. The extent of NH\textsubscript{3} volatilization is determined by soil pH, texture, temperature, moisture, exchangeable cations, fertilizer source and rate of application (Fageria, 2009).

Nutrient efficient genotypes have the potential to produce higher yields per unit of nutrient applied or absorbed as compared to standard genotypes in similar agro-ecologies (Fageria, Baligar, & Li, 2008). Differences in N uptake and utilization among field crops have been reported by Fageria and Baligar (2005). Since rice is a C\textsubscript{3} plant, it has lower NO\textsubscript{3}– uptake capacity than C\textsubscript{4} plants. Nutrient uptake of crop plants is governed largely by their root systems (Nada, Abo-Hegazy, Budran, & Abogadallah, 2019). The difference in nutrient uptake and utilization may be associated with better root geometry, ability of taking up sufficient nutrients from lower concentrations, ability of solubilizing nutrients in the rhizosphere, better transport, distribution, utilization, and balanced source-sink relationship (Fageria & Baligar, 2003). Improvement of nutrient uptake would also be associated with increased yield per unit area, better crop management practices, and crop genotypes having higher yield potentials. Hasan (2014) noted that total N uptake of rice plant ha\textsuperscript{–1} varies among rice varieties. In developing countries, efficient use of inorganic N fertilizer sources is essential for nutrient-efficient varieties to play a vital role in increasing the rice yields per unit area and improve the health and quality of human’s life in the twenty-first century (Fageria et al., 2008).

Fogera Plain in northwest Ethiopia constitutes a huge plain land largely flooded during the main rainy season that allows for expansion and intensification of lowland rice. In the flooded plain of Fogera, hence, there is a need for better management of N fertilizer including the utilization of more efficient N fertilizer sources and lowland rice varieties so as to improve rice productivity in the flooded plain. Conventional urea, which is presently used nitrogen fertilizer source for rice production in Fogera Plain, is claimed not suitable to rain-fed lowland rice production in Fogera Plain. Hence, seeking improved nutrient management practices such as efficient inorganic N fertilizer sources and improved rice varieties with higher N use efficiency capacity are essential for increasing the nitrogen use efficiency and productivity of rain-fed lowland rice in the plain. Thus, the main objective of the present study was to study the response of rain-fed lowland rice varieties to different nitrogen fertilizer sources and forward optimal recommendations of the study for harnessing economically maximum rice productivity in Fogera Plain.

2. Materials and methods

2.1. Description of the study area

The field experiment was carried out in two main rainy-seasons of 2017 and 2018 in Fogera Plain of northwest Ethiopia near Woreta town. Fogera Plain is found in South Gondar Zone of Ethiopia at the distance of 60 km North-East of Bahir Dar city. Fogera Plain is an extended wetland area around Lake Tana, which is the largest lake in Ethiopia. The experimental site is geographically located at 13º19’ North latitude and 37º03’ East longitude with an altitude of 1815 m.a.s.l (Tilahun, Nigussie, Wondimu, & Setegn, 2013). The climatic data of Woreta town, which is situated in the middle of Fogera Plain, show that the mean annual minimum, maximum and mean temperatures of the area are 14.0ºC, 27.7ºC and 20.8ºC, respectively. Rainfall of the area is uni-modal, usually occurring from June to October, and its average annual total over many years is 1363.7 mm (Figure 1). Generally, the long-term weather data showed that trend of rainfall and minimum temperature in the study area is increasing while maximum temperature is decreasing. According to Heluf and Mulugeta (2006), the soil type of Woreta is classified as Pellic Vertisol. The ecology and type of rice cultivation practiced in Fogera Plain is categorized as rain-fed lowland rice culture.

In the figure, ‡, † and †† show the trend equations of annual rainfall amount, average annual minimum and maximum temperatures, respectively. The black bars represent the annual rainfall...
amount in mm. The thin and thick black curves indicate average annual minimum and maximum temperatures in °C, respectively.

To characterize the soil of experimental site, a composite soil sample was taken before plowing the experimental plot by mixing samples collected at eight different spots along the two diagonal lines of the field at 0–20 cm depth using auger. The composite soil sample was air dried and ground to pass through a 2 mm diameter sieve size and used further for analyzing the important physicochemical soil properties including texture, pH, organic content, total nitrogen, available phosphorous, CEC and exchangeable cations (Ca, Mg, K and Na) following their respective standard methods and procedures. The collected soil samples were analyzed at Sirinka Agricultural Research Center soil laboratory. Soil pH was determined using a pH meter in 1:2.5 soil: H₂O ratio as described by Black (1965b). Soil texture was determined by the Bouyoucos hydrometer method (Bouyoucos, 1951). Soil organic carbon was determined by the Walkley–Black wet digestion method (Walkley & Black, 1934). Total N was determined by the Kjeldahl digestion method according to Bremner and Mulvaney (1982). Available soil P was determined using the Olsen NaHCO₃ extraction method (Landon, 1991; Olsen, Cole, Watanable, & Dean, 1954). Cation exchange capacity was determined by the 1N ammonium acetate extraction method as described by Black (1965b). Exchangeable cations (Ca, Mg, K and Na) were extracted with 1N ammonium acetate solution. Sodium and potassium were determined by flame photometer whereas Ca and Mg were determined by atomic absorption spectrophotometer. Available potassium was determined photometrically using the method described by Hunter and Pratt (1957). The soil laboratory analysis results are presented in Table 1.

The textural class of the experimental soil was found to be heavy clay with the pH of 6.08, which is slightly acidic and it is a preferred range for most crops (Table 1). Electrical conductivity of the soil was 0.048ds/m which is less than 4ds/m, indicating none-saline nature of the soil. Total nitrogen content was 0.11%, which is within the range of low levels (0.02–0.5%) for tropical soils. The organic matter content of the soil was 2.39%, which is within a range of medium (2–4%) for Ethiopian soils as per criteria developed by Murphy (1968). The available P content of the experimental soil was 3.58 mg kg⁻¹, which lies in a range of deficiency (<20–40 mg/kg) for most crops (Landon, 1991). Available K content was 240.59 ppm, which lies in a range of high (>175 ppm). CEC of the soil was 61.05, which is ranked from high to very high.

2.2. Experimental treatments and design
Factorial combinations of three N fertilizer sources (conventional urea, slow-release urea and USG) and three rain-fed lowland rice varieties (Hiber, Ediget and X-jigna) were laid out in randomized
complete block design (RCBD) with three replications. All the three N fertilizer sources were applied at the recommended rate of 69 kg N ha$^{-1}$ while all plots were treated with a uniform rate of 46 kg P$_2$O$_5$ ha$^{-1}$ in the form of triple super phosphate (TSP) as P fertilizer source through band application methods at planting time for rice in the study area.

### 2.3. Planting materials

_X-jigna, Hiber_ and _Ediget_ varieties of rain-fed lowland rice were used as planting materials. _X-jigna_ is a local rain-fed lowland rice variety while _Hiber_ and _Ediget_ are improved rain-fed lowland rice varieties. These rice varieties would have suitable environmental factors such as altitudinal ranges in between 1150–1850 masl and rain fall amount of 1000–1400 mm. Those rice varieties would have a seed color of white and an average plant height of 88 cm. Rain-fed lowland rice varieties of _X-jigna, Hiber_ and _Ediget_ would have a maturity date of about 140–150, 105–141 and 120–134 days, respectively (CVRI [Crop Variety Register Issue], 2016).

### 2.4. Experimental procedures and field management

The experimental field was plowed three times by using tractor before sowing. The gross plot size was 2.8 m × 4 m (11.2 m$^2$) with the net plot size of 2 m × 3 m (6 m$^2$). Spacing between adjacent replications and plots was 1.5 m and 0.75 m, respectively. Bunds were made in order to partition between blocks and among plots. This would have the ability to accumulate enough water for rain-fed lowland rice. Seeds of the rice varieties were drilled in rows of 20 cm apart at the recommended seeding rate of 100 kg ha$^{-1}$ for rice in the study area. Important crop data were collected from the net plot area. As per the treatments, the required amount of conventional urea and slow-release urea N fertilizers was applied in two splits in such a way that 1/3 at planting and 2/3 at mid-tillering growth stages of rice crop. Conventional urea during planting was applied in band, }

| Table 1. Relevant soil physicochemical properties of the experimental rice field before planting in Fogera Plain of Ethiopia |
|---------------------------------------------------------------|
| **Soil properties** | **Units** | **Soil depth (0–20 cm)** | **Rating** |
| **Physical properties** | | | |
| Soil texture | | | |
| Sand | % | 9 | |
| Silt | % | 19 | |
| Clay | % | 72 | |
| Textural class | | Heavy clay | |
| **Chemical properties** | | | |
| pH (H$_2$O) 1:2.5 g soil | – | 6.08 | Slightly acidic$^*$ |
| Electrical conductivity (EC) | ds m$^{-1}$ | 0.048 | Very low$^*$ |
| Total nitrogen (TN) | % | 0.11 | Low$^+$ |
| Organic carbon (OC) | % | 1.33 | Medium$^+$ |
| Organic matter (OM) | % | 2.29 | Medium$^+$ |
| Available phosphorus | mg kg$^{-1}$ | 3.58 | Low$^+$ |
| Available potassium | ppm | 240.59 | High$^+$ |
| CEC | cmol kg$^{-1}$ soil | 61.05 | High to very high$^+$ |
| **Exchangeable cations** | | | |
| Ca | cmol kg$^{-1}$ soil | 42.48 | High$^+$ |
| Mg | cmol kg$^{-1}$ soil | 15.10 | High$^+$ |
| K | cmol kg$^{-1}$ soil | 0.38 | Low$^+$ |
| Na | cmol kg$^{-1}$ soil | 2.24 | Low$^+$ |

$^*$ and $^+$ rating according to Murphy (1968) and Landon (1991), respectively.
while it was applied in mud-balls form after planting under waterlogged condition. Both at planting and mid-tillering growth stages, slow-release urea was applied in band along rice rows. To apply slow-release urea at mid-tillering growth stage, the water was drained out first from the experimental plots. One point eight gram pellets (each 1.8 g) of USG were applied once after emergence of rice crop with the recommended deep point placement of 7-10 cm depth into the soil in alternate rows at 30 cm distance from one to another pellet. All other necessary agronomic practices were applied as per their respective recommendations for rain-fed lowland rice in Fogera Plain.

2.5. Data collection
Leaf area index (LAI), SPAD, thousand-grain weight, and above ground biomass and grain yields of rice were considered as main parameters of the study, and their data were collected timely following their respective standard methods and procedures. As growth and physiological variables, LAI and SPAD were measured at flower initiation of rice. To measure LAI, field photograph pictures were taken using digital camera in typical growth stages at flower initiation of rice. The pictures were then imported immediately to the computer for analysis of LAI by using LAI calculator called Hemispheres software (Thimonier, Sedivy, & Schleppi, 2010). Similarly, SPAD-502 chlorophyll meter (Minolta, Osaka, Japan) was used to measure the chlorophyll concentration of rice by taking young fully developed leaves and then five places were selected from 10 plants to take the average from a stage of flower initiation (Gholizadeh, Amin, Anuar, & Aimrun, 2009). It is quick, simple and a non-destructive way of measuring N unlike N prediction through Kjeldahl procedure. At physiological maturity, rice plants were harvested just above ground level from net plot area to determine biomass and grain yields. Biomass yield of rice was weighed with graduated balance after sun drying of harvested plants by taking samples from each plot and oven dried by 65 °c within 24 hours until it comes to constant weight and each plot biomass yield was converted into hectare basis (t ha⁻¹). After sun drying and threshing, grains of each plot were sorted out from straw and debris, and weighted with sensitive balance. Rice grain yield obtained from each net plot area was adjusted to 14% moisture content and converted into hectare basis (t ha⁻¹). Thousand grains weight was determined by taking 250 seeds randomly from net plot produce and weighing with sensitive balance, and expressed in grams. Labor costs incurred for fertilizer application and weeding, and costs for purchasing variable inputs mainly different N fertilizer sources were collected to analyze the cost-benefit of the treatments.

2.6. Data analyses
The collected data were subjected to analysis of variance (ANOVA) using SAS software version 9.2 (SAS-Institute, 2008). Since the test of homogeneity of variances for each parameter was non-significant, combined analysis of variance was also done for each parameters over the years. Whenever the F-test showed significant difference among treatments for a parameter in question, mean separation was performed using Honestly Significant Difference (HSD) method. Cost-benefit analysis of the treatments was carried out by following CIMMYT [Center for Improvement of Maize and Wheat] (1988) procedures by taking all variable costs. Conventional Urea fertilizer cost of 13 Birr per kg, USG and slow-release Urea costs of 15 Birr per kg, the labor cost of 50 Birr per man-day, rice grain price of 13 Birr per kg, and straw price of 1 Birr per kg were considered for the economic analysis.

3. Results and discussion

3.1. Chlorophyll content and leaf area index of lowland rice varieties in response to different N fertilizer sources

3.1.1. Chlorophyll content/SPAD at flower initiation stage
SPAD, which is estimating the chlorophyll content, at flower initiation stage of rain-fed lowland rice was very highly significantly (P < 0.001) affected with different N fertilizer sources and rice varieties in 2018 in Fogera Plain (Table 2). Combined over 2 experimental years (2017 and 2018), different N fertilizer sources and rice varieties had also very highly significantly (P < 0.001) and significantly (P < 0.05) affected the SPAD value, respectively (Table 2). SPAD (chlorophyll content) was not
however significantly \((P \geq 0.05)\) influenced by N fertilizer sources and rice varieties in 2017, and by their interaction in both two cropping seasons and combined over 2 years. Combined over 2 years (2017 and 2018), the highest SPAD value (40.6) of lowland rice was recorded with application of USG N fertilizer followed by conventional Urea (38.8 SPAD). The lowest chlorophyll content of rain-fed lowland rice (36.4 SPAD) was recorded at slow-release Urea treatment (Table 2). Similarly, the highest SPAD value (40.0) of lowland rice was also recorded at rice variety of Hiber followed by Ediget (38.6 SPAD). But, the lowest chlorophyll content of rain-fed lowland rice (37.3 SPAD) was recorded at rice variety of X-jigna (Table 2).

Increasing the SPAD value of lowland rice varieties of Hiber and Ediget with application of Urea supergarnule N fertilizer would most likely be associated with accumulation of higher nitrogen content in rice leaves that eventually contributed for the synthesis of more chlorophylls. These present results are in agreement with similar works reported by Gholizadeh et al. (2009) and Gholizadeh, Saberioon, Boruvka, Wayayok, and Mohd-Soom (2017), Cabangon, Castillo, and Tuong (2011), Hussain et al. (2014), and Alagappan and Venkitaswamy (2015) indicated that SPAD chlorophyll meter paves the way to real-time N management and grain yield estimations for rain-fed lowland rice.

According to Peng et al. (1996), 35 SPAD is considered as critical threshold value, and the rice crop suffers from nitrogen deficiency as SPAD readings fall below 35. In the present study, the SPAD results were not consistent and they were even more lower with the application of slow release urea. These low SPAD results below 40 indicated somewhat deficiency of nitrogen and the recommended rate of nitrogen currently used for rain-fed lowland rice culture in the study area might not be sufficient enough for optimal growth and development of rice plants. Therefore, it is necessary to study further on the responses of rain-fed lowland rice varieties to different nitrogen rates in the study area with a close monitoring of nitrogen status of experimental rice plants with a chlorophyll meter (SPAD) and eventually correlating the SPAD results to the yield parameters for ascertaining of SPAD application for quick nitrogen management in rice fields towards achieving the maximum rice productivity.

### Table 2. Main effects of N sources and rice varieties on SPAD and LAI of rain-fed lowland rice in 2017 and 2018 and combined over years in Fogera Plain of Ethiopia

| Main effects                  | SPAD-FI  | LAI-FI  |
|-------------------------------|----------|---------|
|                               | 2017     | 2018    | COY     | 2017 | 2018 | COY     |
| **Nitrogen sources**          |          |         |         |      |      |         |
| Urea supergarnule             | 35.9     | 45.8a   | 40.9a   | 3.1a | 4.4a | 3.7a    |
| Conventional urea             | 35.4     | 41.7ab  | 38.6ab  | 2.9ab| 3.5b | 3.2ab   |
| Slow-release urea             | 33.1     | 39.7b   | 36.4b   | 2.5b | 3.5b | 3.0b    |
| **Sign. difference**          | ns       | ***     | ***     | *    | *    | ***     |
| SE±                           | 1.2      | 1.3     | 0.8     | 0.2  | 0.3  | 0.2     |
| **Rice varieties**            |          |         |         |      |      |         |
| Hiber                         | 35.6     | 45.8a   | 40.7a   | 3.0  | 4.1a | 3.4     |
| Ediget                        | 34.5     | 41.5ab  | 37.9ab  | 2.7  | 4.0a | 3.4     |
| X-jigna                       | 34.5     | 40.0b   | 37.3b   | 2.8  | 3.3b | 3.2     |
| **Sign. difference**          | ns       | ***     | *       | ns   | *    | ns      |
| SE±                           | 1.2      | 1.3     | 0.8     | 0.2  | 0.3  | 0.2     |
| CV (%)                        | 7.4      | 6.2     | 6.6     | 14.7 | 16.5 | 15.6    |

Means within a column followed by the same letter(s) are not significantly different; *** = very highly significant at \(P < 0.001\); *= significant at \(P < 0.05\); ns = non-significant at \(P \geq 0.05\); COY = combined over years; SPAD-FI = soil plant analysis development at flower initiation; LAI-FI = leaf area index at flower initiation; SE = standard error; CV = coefficient of variation.
3.1.2. Leaf area index at flower initiation growth stage
LAI at flower initiation of rain-fed lowland rice revealed significant (P < 0.05) difference due to the main effect of N fertilizer sources in two cropping seasons (Table 2). There was also significant difference for LAI due to main effect of rice varieties in 2018, but not in 2017 and combined over 2 years (Table 2). Combined over 2 years (2017 and 2018), different N fertilizer sources influenced LAI of lowland rice very highly significantly (P < 0.001). In 2017, 2018 and combined over 2 years, LAI was not significantly (P ≥ 0.05) influenced by the interaction of N fertilizer sources and rice varieties. Combined over 2 years (2017 and 2018), the highest LAI (3.7) of lowland rice was recorded at the treatment of USG followed by slow-release urea (3.2). The lowest LAI (3.0) of rain-fed lowland rice was recorded at the treatment of conventional urea (Table 2). In the same way, the highest LAI (4.1) was also recorded by rice variety of Hiber followed by Ediget (4.0) in 2018 (Table 2). The lowest LAI (3.3) was recorded by rice variety of X-jigna.

Increasing LAI with application of USG in rice varieties of Hiber and Ediget would most likely be associated with the better effect of USG on vegetative growth than other N fertilizer sources that eventually contributed for more ground cover with USG than other N fertilizer sources. This might be due to the fact that the applied N as USG was steadily available to the growing rice plants, which resulted in more vegetative growth than conventional and slow-release urea. Higher LAI due to USG application would further increase the photosynthesis rate of rice plants that might eventually contribute to achieve maximum grain yield of rice. On the other hand, LAI of rain-fed lowland rice with conventional urea and slow-release urea was lower than with that of USG. This low LAI with conventional and slow-release urea might be associated with the loss of the applied N and availability of nitrogen to the rice plants sometime during active vegetative growth of rice plants, might be somewhat lower than the requirement (Amare, Getachew, Enyew, & Tilahun, 2019). Similar results of the present study have also been reported by Hussain et al. (2014) and Zhang et al. (2018). According to Yoshida (1981), the maximum photosynthesis of rice can be attained at the LAI of 5–6.

3.2. Yield response of lowland rice varieties to N fertilizer sources

3.2.1. Thousand grains weight
Thousand grains weight was very highly significantly (P < 0.001) affected by main effect of rice varieties in both cropping seasons of 2017 and 2018 as well as combined over 2 years in Fogera Plain (Table 3). It was also significantly (P < 0.05) affected by the interaction of N fertilizer sources and rice varieties in 2018 (Table 4). Nitrogen fertilizer sources didn’t show significant (P ≥ 0.05) difference for thousand grains weight of rain-fed lowland rice in two cropping seasons and combined over 2 years. Interaction of N fertilizer sources and rice varieties didn’t also significantly (P ≥ 0.05) affected thousand grains weight of rain-fed lowland rice in 2017 and combined over 2 years. In 2018, thousand grains weight of rain-fed lowland rice increased from 24.4 to 32.4g by interaction of N fertilizer sources and rice varieties (Table 4). Similar higher thousand grains weight in 2018 was recorded at the interactions of all the three N fertilizer sources with Hiber and Ediget rice varieties, while lower thousand-grain weight was recorded at the interaction of N fertilizer sources with X-jigna rice variety. The present study showed that significant effects on thousand-grain weight of rain-fed lowland rice were observed due to different lowland rice varieties. This might be due to unsuitable climatic conditions for the productivity of heavy grains for rain-fed lowland rice (Amare et al., 2019). Perhaps, this effect further resulted in more lowered grain weight in panicles of rice plants. In contrast, thousand-grain weights are maintained by genetic potential of the crop and it descents due to severe shortage of vital nutrients (Krishnan, Ramakrishnan, Reddy, & Reddy, 2011; Sarangi et al., 2016). Moreover, this finding is supported by Shi et al. (2016), who reported that high night-time temperature affects the production of more lowered grain weight in the wet-seasons than in the dry-seasons of rice.
3.2.2. Biomass yield
Biomass yield of rain-fed lowland rice was very highly significantly (P < 0.001) affected by main effect of N fertilizer sources in two cropping seasons and combined over 2 years in Fogera Plain (Table 3). Main effect of rice varieties and its interaction effects of different N fertilizer sources did not show significant (P ≥ 0.05) difference on biomass yield of rain-fed lowland rice in two cropping seasons and combined over 2 years. Combined over 2 years (2017 and 2018), the highest biomass yield (13.2 t ha⁻¹) of lowland rice was recorded at the treatment of USG (Table 3). The lowest biomass yield (9.1 t ha⁻¹) of lowland rice was recorded at the treatment of slow-release urea followed by conventional urea (10.0 t ha⁻¹). From the present study, increasing biomass yield of rain-fed lowland rice with USG would most likely be associated with growth and yield parameters simultaneously increase (Amare et al., 2019). Nitrogen is essential for plant growth since it is a constituent of all proteins and nucleic acids. These present results agree with findings of some workers (Fengqin, Huoyan, Pu, & Jianmin, 2018; Guo et al., 2018; Hussain et al., 2014; Sarangi et al., 2016).

3.2.3. Grain yield
Grain yield of rain-fed lowland rice was significantly (P < 0.05) affected by main effect of N fertilizer sources in 2017 and very much significantly (P < 0.001) affected by main effect of N fertilizer sources in 2018 and combined over 2 years in Fogera Plain (Table 3). In two cropping seasons and combined over 2 years (2017 and 2018), grain yield showed highly significant (P < 0.01) and very highly significant (P < 0.001) differences by main effect of rice varieties, respectively (Table 3). In contrast, grain yield was also significantly (P < 0.05) affected by interaction effects of N fertilizer sources and rice varieties in 2017 and highly significantly (P < 0.01) affected by interaction effects in 2018 and combined over 2 years (Table 4). The average results of two cropping seasons showed that the highest grain yield (4.6 t ha⁻¹) of lowland rice was recorded at the interaction of USG by rice variety of Hiber (Table 4). The lowest grain yield (2.7 t ha⁻¹) of lowland rice was recorded at the interaction effects of conventional urea by X-jigna followed by slow-release urea by Ediget (3.0 t ha⁻¹) and slow-release urea by X-jigna (3.1 t ha⁻¹).

| Main effects | TGW 2017 | 2018 | COY | BYt 2017 | 2018 | COY | GYt 2017 | 2018 | COY |
|--------------|----------|------|-----|----------|------|-----|----------|------|-----|
| Nitrogen sources |          |      |     |          |      |     |          |      |     |
| USG          | 26.2     | 29.5 | 27.9| 9.3a     | 17.1a| 13.2a| 2.6a     | 5.2a | 3.90a|
| CU           | 27.1     | 30.0 | 28.5| 7.6ab    | 12.4b| 10.0b| 2.4a     | 4.3b | 3.35b|
| SRU          | 25.9     | 30.7 | 28.3| 6.3b     | 12.0b| 9.1b | 1.8b     | 4.5b | 3.16b|
| Sign. difference | ns | ns | ns | *** | *** | *** | * | *** | *** |
| SE±          | 1.1      | 0.7  | 0.7 | 0.6      | 1.1  | 0.6  | 0.2      | 0.2  | 0.1  |
| Rice varieties |           |      |     |          |      |     |          |      |     |
| Hiber        | 29.2a    | 31.5a| 30.3a| 7.8     | 13.7 | 10.7 | 2.7a     | 5.0a | 3.8a |
| Ediget       | 27.4a    | 31.8a| 29.6a| 7.6     | 14.0 | 10.8 | 2.6a     | 4.5b | 3.5ab|
| X-jigna      | 22.8a    | 26.8b| 24.8b| 7.8     | 13.8 | 10.8 | 1.7b     | 4.4b | 3.1b |
| Sign. difference | *** | *** | *** | ns | ns | ns | ** | ** | *** |
| SE±          | 8.5      | 5.1  | 6.9 | 15.5     | 16.4 | 16.3 | 21.8     | 7.4  | 12.0 |

Means within a column followed by the same letter(s) are not significantly different; *** = very highly significant at P < 0.001; ** = highly significant at P < 0.01; * = significant at P < 0.05; ns = non-significant at P ≥ 0.05; COY = combined over years; USG = urea supergranule; CU = conventional urea (with mud-balls); SRU = slow-release urea; TGW = thousand-grain weight (g); BYt = biomass yield (ton ha⁻¹); GYt = grain yield (ton ha⁻¹); SE = standard error; CV = coefficient of variation.

3.2.2. Biomass yield
Biomass yield of rain-fed lowland rice was very highly significantly (P < 0.001) affected by main effect of N fertilizer sources in two cropping seasons and combined over 2 years in Fogera Plain (Table 3). Main effect of rice varieties and its interaction effects of different N fertilizer sources did not show significant (P ≥ 0.05) difference on biomass yield of rain-fed lowland rice in two cropping seasons and combined over 2 years. Combined over 2 years (2017 and 2018), the highest biomass yield (13.2 t ha⁻¹) of lowland rice was recorded at the treatment of USG (Table 3). The lowest biomass yield (9.1 t ha⁻¹) of lowland rice was recorded at the treatment of slow-release urea followed by conventional urea (10.0 t ha⁻¹). From the present study, increasing biomass yield of rain-fed lowland rice with USG would most likely be associated with growth and yield parameters simultaneously increase (Amare et al., 2019). Nitrogen is essential for plant growth since it is a constituent of all proteins and nucleic acids. These present results agree with findings of some workers (Fengqin, Huoyan, Pu, & Jianmin, 2018; Guo et al., 2018; Hussain et al., 2014; Sarangi et al., 2016).

3.2.3. Grain yield
Grain yield of rain-fed lowland rice was significantly (P < 0.05) affected by main effect of N fertilizer sources in 2017 and very much significantly (P < 0.001) affected by main effect of N fertilizer sources in 2018 and combined over 2 years in Fogera Plain (Table 3). In two cropping seasons and combined over 2 years (2017 and 2018), grain yield showed highly significant (P < 0.01) and very highly significant (P < 0.001) differences by main effect of rice varieties, respectively (Table 3). In contrast, grain yield was also significantly (P < 0.05) affected by interaction effects of N fertilizer sources and rice varieties in 2017 and highly significantly (P < 0.01) affected by interaction effects in 2018 and combined over 2 years (Table 4). The average results of two cropping seasons showed that the highest grain yield (4.6 t ha⁻¹) of lowland rice was recorded at the interaction of USG by rice variety of Hiber (Table 4). The lowest grain yield (2.7 t ha⁻¹) of lowland rice was recorded at the interaction effects of conventional urea by X-jigna followed by slow-release urea by Ediget (3.0 t ha⁻¹) and slow-release urea by X-jigna (3.1 t ha⁻¹).
| Interaction effects | TGW 2017 | COY 2017 | GYt 2017 | TGW 2018 | COY 2018 | GYt 2018 |
|---------------------|----------|----------|----------|----------|----------|----------|
| **Nitrogen sources** |          |          |          |          |          |          |
| Urea supergranule   |          |          |          |          |          |          |
| Hiber               | 29.6     | 31.7ab   | 30.7     | 3.7a     | 5.5a     | 4.6a     |
| Ediget              | 25.4     | 32.4a    | 28.9     | 2.6bc    | 4.8ab    | 3.7bc    |
| X-jigna             | 23.7     | 24.4c    | 24.0     | 1.6d     | 5.2ab    | 3.4bc    |
| Conventional urea   |          |          |          |          |          |          |
| Hiber               | 29.3     | 32.1ab   | 30.7     | 2.3b-d   | 4.7bc    | 3.5b-d   |
| Ediget              | 29.8     | 31.2ab   | 30.5     | 3.1ab    | 4.7bc    | 3.9b     |
| X-jigna             | 22.2     | 26.5c    | 24.4     | 2.0cd    | 3.4d     | 2.7e     |
| Slow-release urea   |          |          |          |          |          |          |
| Hiber               | 28.6     | 30.8ab   | 29.7     | 2.1cd    | 4.8ab    | 3.5b-d   |
| Ediget              | 27.0     | 31.9ab   | 29.4     | 2.0cd    | 3.9cd    | 3.0de    |
| X-jigna             | 22.3     | 29.5b    | 25.9     | 1.4d     | 4.7bc    | 3.1c-e   |
| **Sign. difference**| ns       | *        | ns       | *        | **       | **       |
| **SE±**             | 1.8      | 1.2      | 1.1      | 0.4      | 0.3      | 0.2      |
| **CV (%)**          | 8.5      | 5.1      | 6.9      | 21.8     | 7.4      | 12.0     |

Means within a column followed by the same letter(s) are not significantly different; ** = highly significant at \( P < 0.01 \); * = significant at \( P < 0.05 \); ns = non-significant at \( P \geq 0.05 \); COY = combined over years; TGW = thousand grain-weight (g); GYt = grain yield (ton ha\(^{-1}\)); SE = standard error; CV = coefficient of variation.
In this study, N fertilizer sources of USG applications increased grain yield of lowland rice variety of *Hiber* by 50 to 70% as compared to the lowest treatment. Applications of USG had a marked effect on grain yield of rain-fed lowland rice compared to slow-release urea and conventional urea (Amare et al., 2019). The yield performance of rain-fed lowland rice varieties of *Hiber* was higher than *Ediget* and *X-jigna* with all N sources of fertilizer. The increasing effect of grain yield of lowland rice varieties with applications of different N fertilizer sources could be mainly due to increasing SPAD value, LAI, biomass yield and thousand-grain weight in this study. These findings are in agreement with the results obtained from mineral fertilizer studies on rice (Rose et al., 2018). Guo et al. (2018) also reported findings indicating that improvements in grain yields attributed to increments in yield components. According to Singh et al. (2016) vigorous vegetative growth of rain-fed lowland rice promoted by N sources of fertilizer applications resulted in higher grain yield by favoring higher biomass yield. Increasing in yield components are associated with better nutrition, plant growth and increased nutrient uptake (Adviento-Borbe & Linquist, 2016; Bandaogo et al., 2015; Fengqin et al., 2018; Li et al., 2018; Meng et al., 2017). Variety improvement has the potential to raise rice yield and grain quality (Subudhi et al., 2020; Xiao-hua & Rui-fa, 2017). In the same way, improved variety and improved management practices resulted in increasing rice yield in many countries (Choudhary & Suri, 2014; Sarangi et al., 2016). Arouna, Lokossou, Wopereis, Bruce-Oliver, and Roy-Macauley (2017) reported that improved varieties have the contribution to poverty reduction and food security besides to yield increment in Sub-Saharan Africa. Jian-chang, Hao, and Jian-hua (2012) also stated that different rice varieties of root morphology and physiology are connected to increase grain yield in rice. This was in concomitant with the findings of Pan et al. (2017) and Koudjega et al. (2019) stated that deep and point placement of urea could increase nitrogen use efficiency by reducing nitrogen losses and confirms prolonged nitrogen availability up to the final maturity stage and further led to more roots were distributed within the lower soil layer of rain-fed lowland rice field.

3.3. Cost benefit analyses of N sources of fertilizer and lowland rice varieties production

To assess the costs and benefits associated with different treatments, partial budget analyses were carried out by taking mean grain yield and prices of input and output of N fertilizer sources and rice varieties in reference to the nearby Woreta market (Table 5). Marginal rates of return (MRR) were calculated by adjusting grain yield of rice by 10% to narrow the yield gap between research and farmers’ fields (CIMMYT, 1988). All costs and benefits were calculated on a hectare basis in Ethiopian Birr (EB ha⁻¹). As a result, USG by *Ediget* and USG by *Hiber* treatments are accepted in the present study which gave higher MRR and net benefits (48,817.40 and 58,947.50 EB ha⁻¹), respectively, over that of other

| Treatments | N sources | Rice varieties | MGY | AGY | TVC | GFB | NB | MRR  |
|------------|-----------|----------------|-----|-----|-----|-----|----|------|
|            | USG       | *Hiber*        | 4.6 | 4.1 | 3803.80 | 62,751.30 | 58,947.50 | 35,363.1 |
|            |           | *Ediget*       | 3.7 | 3.3 | 3775.20 | 52,592.60 | 48,817.40 | 35,363.1 |
|            |           | *X-jigna*      | 3.4 | 3.1 | 3775.20 | 49,728.90 | 45,953.70 | 45,953.70D |
|            | CU        | *Hiber*        | 3.5 | 3.1 | 4204.30 | 46,546.80 | 42,342.50 | 42,342.50D |
|            |           | *Ediget*       | 3.9 | 3.5 | 4262.50 | 52,627.70 | 48,365.20 | 48,365.20D |
|            |           | *X-jigna*      | 2.7 | 2.4 | 4320.70 | 38,500.00 | 34,179.30 | 34,179.30D |
|            | SRU       | *Hiber*        | 3.5 | 3.1 | 4469.60 | 46,674.50 | 42,004.90 | 42,004.90D |
|            |           | *Ediget*       | 3.0 | 2.7 | 4238.70 | 39,931.90 | 35,693.20 | 35,693.20D |
|            |           | *X-jigna*      | 3.1 | 2.8 | 4382.80 | 42,641.00 | 38,258.20 | 38,258.20D |

CU = conventional urea (with mud-balls); USG = urea supergranule; SRU = slow-release urea; MGY = mean grain yield (ton ha⁻¹); AGY = adjusted grain yield (ton ha⁻¹); TVC = total variable costs (Ethiopian Birr ha⁻¹); GFB = gross field benefit (Ethiopian Birr ha⁻¹); NB = net benefit (Ethiopian Birr ha⁻¹); MRR = marginal rate of return (%); D = dominated treatment.
treatments. Accordingly, using USG for Hiber and Ediget rice varieties of rain-fed lowland rice under the prevailing price structure can be as promising new practice for farmers in Fogera Plain.

4. Conclusions

Results of the present study showed differences between N fertilizer sources and varieties as well as their interactions in different magnitude for growth and yield of rain-fed lowland rice in Fogera Plain, Ethiopia. In this study, mud-balls making of conventional urea was found to be very tedious and labor consuming work, and its yield and economic performances were not outmaneuvered over that of USG and slow-release urea. Based on the results of the present study, it is hence recommendable to use more efficient and labor saving USG N fertilizer and lowland rice varieties of Hiber and Ediget as the first and the second outmaneuvered combinations for getting better grain yield and net benefit of rain-fed lowland rice production in Fogera Plain, Ethiopia.

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