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Research Article

Nitrogen Use Efficiency of Upland Rice in the Humid Tropics of Southwest Ethiopia in Response to Split Nitrogen Application

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Abstract

Background and Objective: Synchronizing timing of N-fertilizer application with rice crop nitrogen (N) demand is an important factor in determining soil N availability, crop N content and uptake capacity and yield of upland rice (*Oryza sativa* L.). Therefore, this study was designed to determine the effect of variations in N timing and splitting on grain yield, grain N content and N uptake and use efficiency in upland rice varieties on nitisols under rain-fed conditions of Jimma. **Materials and Methods:** A 2 years field experiment in rain-fed acidic soil was designed to study the effect of timing and splitting of nitrogen on N use efficiency of three improved rice varieties (Gumara, Ediget and NERICA-4) at Jimma, Southwest Ethiopia. A single rate of 64 kg N ha^{-1} was splitted in different growth stages of the crop in various proportions between sowing, active tillering and panicle initiation. The experiment was designed in randomized complete block with 3 replications. **Results:** Significant grain yield increases were achieved with split applications of N fertilizer when N was top dressed during active tillering and panicle initiation stages compared to all the remaining N-timing treatments. Nitrogen uptake efficiency was greatest with split application of N when N was top dressed at active tillering stage. Soil N concentration was significantly higher when N was applied at tillering stage compared to other applications. **Conclusion:** Application of N fertilizer to rice preferably as top dressing between active tillering and panicle initiation is a strategy to be recommended from the standpoint of both the environment and of farmer returns.

Key words: Active tillering, N timing and splitting, N use efficiency, panicle, upland rice

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Rice belongs to the Grass family. It is a vital food crop because half of the world's population feeds rice as a main part of their diets. It provides more calories per hectare than any other cereal grain. In Ethiopia, rice is a highly valued crop and is primarily grown for food[1].

Nitrogen is normally a key factor in achieving optimum rice yields. Plant use efficiency of nitrogen depends on several factors, including application time, rate of N applied, precipitation and other climate-related variables. As nitrogen fertilizers are highly dynamic in soils, its careful management was needed, while grain yields and crop uptake efficiency increased[2]. For obvious economical and environmental reasons, N application must be managed very carefully. When N was supplied from commercial fertilizers, it should be applied at a rate that does not greatly exceed the expected crop N requirement. It should be applied as near as possible by the time when the plant need to reduce the chance for potential losses and to prevent undue nutrient enrichment of the environment[3].

Decisions regarding fertilizer application timing pose a major challenge to the farmer, given the complexity and the random character of the problem, the nature of the challenge was becoming different every year. N requirements of major cereals prior to tillering are really low, not exceeding 10% of the total[2]. Hence, the decisions on the timing and splitting of N application must take into account the potential influence of rainfall and leaching of NO_3-N and the critical need for N between tillering and stem elongation.

One possible approach is reducing pre-heading rates of N and top dressing N later in the season[4]. It has been assumed and to some extent documented, that crop N uptake capacity was generally low at the beginning of the growing season, increasing rapidly during vegetative growth and dropping sharply as the crop approaches maturity. Hence, synchronous timing of fertilizer N application with plant N demand was an important factor in determining soil N availability, crop N content and uptake capacity, dry matter and yield of rice crop.

A number of experiments over the last few decades have investigated the effect of N application practices (e.g., form of N applied, rate, splitting and timing) on the fate of N applied and crop output. They have shown that the time of application of fertilizer N significantly influences the use of N by the crop[5]. On the other hand, large number of studies found that low fertilizer use efficiencies have been attributed to the timing of application, especially where fertilizer N was applied during the periods of heavy rainfall. The decline in efficiency of N use, N uptake and N availability with increased rainfall was an indicative of substantial losses and justifies reducing N rates in the rainfall, particularly in situations where residual N levels are high. N applications as top dressing prior to stem elongation increased fertilizer N recovery in wheat, while maintaining or increasing N use efficiency as compared to all late season applications[5].

The recovery of N by cereal crops was often used as a measure of the efficiency of N fertilizer use. Field trials in Central Europe have recorded an average of 50-60% recovery of N fertilizer applied to winter wheat (grain and straw)[6]. The large variations in crop N recovery rates reported by different studies may be due to differences in fertilizer sources, applications rates, climate, variety used and management practices. In arid and semi-arid regions, much of the fertilizer nitrogen not absorbed by the crop in years with inadequate rainfall may remain in the soil as nitrate available to subsequent crops[7]. Craswell and Godwin[7] found that considerable amounts of fertilizer N accumulate as nitrate in the soil profile in arid and semi-arid regions, particularly when high rates of N are applied. The fate of this residual will depend on the incidence of water logging, which causes denitrification.

In rain-fed conditions, N use efficiency at harvest generally ranges from 20-80%, depending on various factors, such as fertilizer type, application time and method, soil type and weather conditions[8]. According to Walker *et al.*[6], the average N use obtained in tropical and sub-tropical regions was generally lower than that of temperate regions.

Despite its very recent history of cultivation in Ethiopia and inspite of the fact that rice was one of the potential grain crops that could contribute to the efforts for the realization of food security in the country, in-depth research study to improve the grain yield has not yet been undertaken apart from few studies done on different N rates on few rice cultivars. Results of studies in this regard illustrated that there are various N efficient rice varieties in Ethiopia which exhibit improved dry matter and grain yields[9]. Apart from the rates, assessing specific timing and split applications for upland rice varieties is crucial. Much of the research in this regard has been carried out in temperate climates. There was a need to study the fate of N fertilizer in the tropical environments particularly in Ethiopia and more information was required on the response of upland rice to changes in the timing of N fertilizer applications.

Understanding the N use efficiency in the humid tropical soils and how it was affected by splitting and variety would provide a scientific basis for rationally applying and appropriately assessing the environmental impacts of N fertilizers. It was hypothesised that split N application would improve both N uptake and yield of upland rice. Therefore, this study was designed with the objective to determine the effect of variations in N timing and splitting on grain yield, grain N content and N uptake and use efficiency in upland rice varieties on Nitisols under rain-fed conditions of Jimma.

MATERIALS AND METHODS

Experimental site description: Field experiments were conducted at Eladale Research Site of the College of Agriculture and Veterinary Medicine, Jimma University, Ethiopia in 2014 and 2015 main cropping season. The area is located at 7°42'N latitude and 36°48'E longitude. The altitude of the experimental site is 1813 m a.s.l. The climate of the area was characterized by a long rainy season (May-September) accounting for about 85% of the annual rainfall having a peak falls in August. The average annual rainfall amounts to 1580 mm in which the length of growing period ranges between 110-130 days. The longer rainy seasons generally have more rainfall and are more reliable than the shorter rainy season (March-April). In most of the time, the dry season occurs between November and February. In recent years, however, the area has experienced a great variability in terms of occurrence and amount of rainfall causing crop failures on several occasions (personal observation).

Treatments and experimental design: Three different rice varieties (Ediget, Gumara and NERICA-4) were examined. Four different combinations of split N applications were arranged as follows. Granular urea fertilizer at a rate of 64 kg ha^{-1} was applied during planting and top-dressed at various growth stages of the crop as indicated below.

- 50% at sowing and 50% at active tillering stage..N_1
- 25% at sowing+50% at active tillering stage and 25% at panicle initiation.................................N_2
- 25% at sowing+25% at active tillering stage and 50% at panicle initiation.................................N_3
- 33% at sowing+33% at active tillering stage and 33% at panicle initiation.................................N_4

Active tillering stage is the stage in rice growth when the plant attains the first 3 tillers whereas panicle initiation is the stage in which panicle primordia starts protruding. As NERICA-4 is the recommended rice variety in South-west Ethiopia based up on the previous studies, this variety at N_1 (½ at sowing and ½ at active tillering stage) was taken as a local check. The treatment includes factorial combinations of three rice varieties along with various timing and splitting of nitrogen (N). A control plot receiving zero N was also included to calculate agronomic use efficiency and apparent N recovery.

The experiment was laid out in a randomized complete block design (RCBD) with factorial arrangement in 3 replications. Each plot was 2.5 m long and 2 m wide and had a total size of 5 m^2 with 8 rows spaced 25 cm. Seeds were sown on rows with manual drilling at a rate of 60 kg ha^{-1}. The middle 6 rows (2.5 m × 1.5 m = 3.75 m^2) were used for yield and its associated traits.

Crop management: Three rice varieties (Gumara, Ediget and NERICA-4) along with urea and triple superphosphate (TSP) fertilizers were used. All the rice varieties were introduced primarily from IRRI (International Rice Research Institute) and WARDA (West Africa Rice Development Association) and evaluated at different locations of the country and released in different years[10].

The three rice varieties were examined against the various N-timing combinations. All the varieties perform well in altitude ranging between 1740-1900 m and rainfall range of 1200-1520 mm. NERICA (New rice for Africa) variety was introduced from WARDA whereas Gumara and Ediget were introduced from IRRI[10].

Full basal dose of TSP granule fertilizer at a rate of 46 kg ha^{-1} P_2O_5 (20% P), a national blanket recommendation for cereal crops on nitisols, was applied during sowing to all the plots uniformly to minimize the crop phosphorus deficiency every year. Weeds were removed by hand 4 times (at early, active and maximum tillering stage and before panicle initiation stages). No insecticide or fungicide was applied since no serious insect or disease incidences were occurred. Harvesting was done manually using hand sickles during the crop's physiological maturity stage.

Soil sampling and analysis: Surface soil samples (approximately 30 cm depth) were collected randomly in a zigzag pattern using auger before treatment application from the entire experimental field of 20 spots and finally one composited sample was considered for analysis. The soil sample analysis for specific parameters relevant to the current study was carried out at the soil laboratory of JUCAVM and analyzed for its particle size distribution (pipette method), pH (in H_2O), total nitrogen[7], available phosphorus[9], organic carbon[6] and CEC[11]. Accordingly, the pre-sowing soil analysis showed that the experimental soil has a pH (H_2O) of 5.80 (moderately acidic). Roy *et al.*[12] reported that the preferable pH ranges for most grain crops and productive soils are in

Table 1: Selected physical and chemical properties of the experimental soil (pre-sowing)

	Values			
	Year			
Parameters	2014	2015	Methods	Status
Particle size distribution (%)				
Sand	29.00	29.00	Pipette method	
Silt	38.00	38.00		
Clay	33.00	33.00		
Textural class				Clay loam
pH in 1:2.5 soils to water suspension	5.82	5.80	Glass electrode pH meter	Moderately acidic (both years)
Organic matter (%)	6.50	6.45	Walkley and black method	Very high (both years)
Available phosphorus (ppm)	2.15	2.02	Bray method	Very low and deficient (both years)
Total nitrogen (%)	0.20	0.224	Micro Kjeldahl method	Medium (both years)
CEC (cmol kg^{-1})	15.50	16.00	Ammonium acetate (NH_4AOc) method	Medium (both years)

CEC: Cation exchange capacity

between 4 and 8. Thus, the pH of the experimental soil was within the range of productive soils and suitable for rice cultivation. Textural class of the soil is clay loam having compositions of 33% clay, 38% silt and 29% sand, which is in the textural class of clay loam in which it was suitable for rice as well as for other agricultural crops[9].

Total nitrogen and organic matter contents of the experimental site soil were 0.224 and 6.45%, respectively (Table 1). According to Dewis and Freitas[13], the nitrogen and organic matter contents of the soils are medium and very high, respectively. Percent organic matter was a measurement of the amount of plant and animal residue in the soil. Accordingly, higher amount of fragments of live and decomposing root tissues of crops and biological N fixation by various crops grown under sequential cropping since long time at the experimental field might have contributed to higher total N and organic matter contents of the surface soil.

Available phosphorus of the soils was 2.02 ppm (Table 1) and according to Landon[14], the experimental soil was found to be very low and deficient in phosphorus. As the area is located in hot sub-humid tropical environments receiving relatively high rainfall, soils were found to be moderately acidic (pH = 5.81) and as a result P is probably fixed by high concentrations of iron and aluminium.

Cation exchange capacity (CEC) was found to be medium (15.5-16). The CEC describes the potential fertility of soils and indicates the soil texture, organic matter content and the dominant types of clay minerals present. In general, soils high in CEC are considered as agriculturally fertile. According to Landon[14], top soils having CEC greater than 40 cmol (+) kg^{-1} are rated as very high and 25-40 cmol (+) kg^{-1} as high and in between 4 and 25 as medium. Accordingly, the soil of the study site is medium in its CEC, which was a reflection of high clay (33%) and high organic carbon (7.6%) contents (Table 1). In general, the pre-sowing experimental soil analysis ensures that the area was suitable for rice cultivation[11].

After maturity, four randomly selected 0.5 m sample lengths per net plot area were harvested at ground level, air-dried and partitioned into straw and grain. The grain and straw sub-samples were ground, sieved through 1 mm size sieve and their N concentration was determined using the procedures indicated above.

Data on crop phenology, yield and yield related parameters: Observation and data record for all traits studied was made based on the Standard Evaluation System for rice[10]. Accordingly, days to 50% heading was recorded when 50% of the plants headed and exerted panicles. Days to 90% physiological maturity was recorded when 90% of the plant population attained yellow coloration and whole grain was hard and ready for harvest. Plant height was determined by measuring the lengths of 10 randomly tagged plants from the ground level to the top of the panicle just before physiological maturity. Number of tillers/plant, number of panicles/plant from ten randomly tagged plants was recorded. Panicle length was measured from the neck node to the tip of panicle on 10 tagged plants just before physiological maturity. Number of fertile and unfertile spikelets per panicle was determined at harvest by taking ten tagged plants including tillers from each plot.

At physiological maturity, the plants were harvested close to the ground level by hand using sickles. Grain yield was measured by threshing the plants harvested from the middle 6 rows (2.5 m × 1.5 m = 3.75 m^2) of each plot to avoid border effects. The moisture content of the rice seeds was determined using a moisture tester at the time of the measurement of the grain yield. Grain yield was then recorded on 14% seed moisture content basis. Straw yield was determined as the difference between the total above ground biological (straw plus grain) recorded after air drying at harvest and the grain yield of the respective treatments. Thousand grains weight was determined by counting thousand kernels from bulked grain samples in each plot and recorded on 14% seed moisture content basis. Harvest index was obtained from the ratio of grain yield to the grain plus straw yield of each plot and expressed as percentage.

Nitrogen concentration, uptake and utilization in tissues of rice crop: The nitrogen contents of the grain (GN%) and straw (SN%) were determined by the micro-Kjeldahl method using grain and straw sub-samples (Craswell and Godwin,[7]). Straw and grain N uptake values, SNU and GNU, respectively, were calculated by multiplying the grain and straw yields by the respective N contents. Total N uptake (TNU) of each sample was calculated as the sum of the respective GNU and SNU values.

The following N-efficiency parameters were calculated for each treatment (all terminologies were taken from Alcoz *et al*.[8] and Fischer *et al*.[15]:

$$\text{N use efficiency (NUE)} = \frac{\text{Grain yield}}{\text{N supply}}$$

$$\text{N uptake efficiency (NU}_{\text{P}}\text{E)} = \frac{\text{Total N uptake}}{\text{N supply}}$$

where, N supply is the sum of soil N at sowing and amount of N applied:

$$\text{N utilization efficiency (NU}_{\text{t}}\text{E)} = \frac{\text{Grain yield}}{\text{Total N uptake}}$$

$$\text{N harvest index (NHI, \%)} = \frac{\text{Grain N uptake}}{\text{Total N uptake}}$$

$$\begin{matrix}\text{Apparent N recovery}\\ \text{(ANR, \%)}\end{matrix} = \frac{\text{Total N uptake at Nx} - \text{Total N uptake at N0}}{\text{Applied N at Nx}}$$

$$\begin{matrix}\text{Agronomic N use}\\ \text{efficiency (AUE, \%)}\end{matrix} = \frac{\text{Grain yield at Nx} - \text{Grain yield at N0}}{\text{Applied N at Nx}}$$

Statistical analysis: Homogeneity of error variance and normality of each character was tested for each year and were found to have normal distributions and the F-test result indicated that most traits except unfertile spikelets/panicle showed non-significant differences. Thus, combined analysis of variance by using SAS 9.0[16] was performed for all the traits except unfertile spikelets/panicle. Combined analysis of variance for unfertile spikelets per panicle was performed separately for each year and its interpretation was given accordingly. The differences between treatment means were compared using least significance difference (LSD) test at 5% level of significance.

RESULTS AND DISCUSSION

Weather conditions: Monthly rainfall and temperatures at the experimental site over the 2 years study has been studied. The amount of rainfall varied considerably more between months in any given year than yearly variation. Due to the event of El-Nino in 2015, there has been an erratic rainfall in various months, consequently, the mean annual rainfall showed inter annual variation of only 13.8 mm in 2015. This was due to the fact that, the number of rainy days within a month varied considerably from 2014-2015.

Rainfall distribution also differed between the 2 years. In 2014, a mean 24% of total rainfall was recorded prior to rice-sowing (June), rainfall was scarce till the last week of June, 7%, while rainfall was adequate during the maturity days (July-October) which accounted for 51% of total annual precipitation. Then after, in November and December, rainfall was reduced amounting to less than 2% of the total annual precipitation.

In contrast, in 2015 the onset was around 1st week of May, but, there was uneven distribution of rainfall till last week of August. Although, the amount varies, there was precipitation starting from first week of April to last week of August. During the maturity days of the crop, rainfall was abundant accounted for 66% of the total annual precipitation. Then after, precipitation was reduced with a mean value of less than 6% in November and December. This considerable monthly variation in rainfall along with the current event of El-Nino consistently reflected in fluctuations in rice growth and yield related parameters.

Differences in temperature between the 2 study years were relatively modest. Mean maximum temperature during the growing period ranged between 26.1-27.3°C over the 2 years period whereas mean minimum temperature during the course of the study ranged between 10.5-14.8°C in 2014 and between 12.2-14.1°C in 2015. During the grain filling period (August-October), the mean minimum temperature was 13.7°C in 2014 while for the year 2015, it was 13.2°C. The mean maximum temperature during these periods was in between 25.3-28.7°C.

Crop phenology and growth parameters: Although, N-timing differs, Ediget and NERICA-4 varieties were uniform in attaining their days to 50% heading which were 122 and 109 days, respectively. However, Gumara variety took 141 days to attain its 50% days to heading (Table 2). According to the reports from the research centres where the varieties were released, the mean days to 50% heading for NERICA-4, Gumara and Ediget was all shorter as compared to the findings obtained in this study. The probable reason for this variation was due to the base temperature requirement of the crop. Base temperature is the minimum temperature whereby metabolic processes result in a net substance gain in aboveground biological. It was an essential parameter for determining the beginning and the end of the growing season.

If not all, most rice varieties generally require an average temperature of above 22°C during their growth period. Rice crop requires minimum night temperature of 13-15°C and if this minimum night temperatures extended over two to three nights during the panicle initiation and continues up to flowering periods, it results in reduced panicle branching and massive pollen and floret sterility[17]. During the tillering stage of the crop, the mean minimum temperature recorded was 10.7°C, which was below the crop's minimum temperature requirement which in turn delayed days to heading. Ediget is shorter (59 cm) as compared to the two varieties (NERICA-4 and Gumara) in which the two varieties are uniform in their mean plant heights (Table 2). Plant height is an important yield related parameter which was reported to be a genetic character that was influenced least by environmental factors such as nutrients and others[18].

Table 2: Effects of rice varieties on days to 50% heading and plant heights at Jimma, 2014-2015

Varieties	Days to 50% heading	Plant heights (cm)
Ediget	121.80^{b}	59.0^{b}
Gumara	140.80^{a}	62.7^{a}
NERICA-4	108.30^{b}	62.5^{a}
$LSD_{(0.05)}$	17.22	3.2
CV (%)	16.50	6.1

Means sharing the same letter(s) in the column do not differ significantly at 5% p level according to the LSD test, LSD: Least significant difference, CV: Coefficient of variation

Interaction of varieties and N-timings had a marked effect on number of tillers/plant in which Gumara scored the maximum number of tillers/plant at all N-timings (Table 3). Whereas, Ediget and NERICA-4 are statistically uniform in their number of tillers plant at all N-timings. Supply of N at various timings and splitting in grain crops was known to favour tillering, although tillering capacity mainly depends up on genotype and seed density[17].

Although, the interaction is significant (Table 4), panicle length was less sensitive to variety and N fertilizer timing (Table 3). Both fertile spikelets/panicle and total number of spikelets/panicle behaved similarly with no statistical differences between the varieties and different N timing treatments (Table 3). According to the reports of the research centre where the varieties were released, Ediget was reported to be cold tolerant variety whereas, Gumara and NERICA-4, were reported to be less sensitive to low temperature as these has a great implication in spikelet fertility.

Table 3: Interaction effect of varieties and N-timings on growth parameters of rice at Jimma, 2014-2015

Varieties	N-timing	Tillers/plant (number)	Panicle length (cm)	Fertile spikelets/panicle (number)	Biological yield (kg ha^{-1})
Ediget	N_1 (½-½-0)	7.1^{c}	14.5^{cd}	25.7^{e}	3200.0^{bc}
	N_2 (¼-½-¼)	6.7^{c}	14.7^{cd}	27.5^{de}	2600.0^{c}
	N_3 (¼-¼-½)	7.1^{c}	13.7^{d}	25.2^{e}	2900.0^{c}
	N_4 (1/3-1/3-1/3)	7.7^{c}	14.4^{cd}	30.9^{cde}	2750.0^{c}
Gumara	N_1 (½-½-0)	18.8^{a}	17.3^{ab}	52.5^{ab}	6350.0^{a}
	N_2 (¼-½-¼)	21.0^{a}	15.8^{bcd}	57.3^{a}	6450.0^{a}
	N_3 (¼-¼-½)	15.0^{ab}	16.1^{bc}	41.7^{abcde}	5400.0^{ab}
	N_4 (1/3-1/3-1/3)	19.2^{a}	16.3^{bc}	43.9^{abcd}	6400.0^{a}
NERICA-4	N_1 (½-½-0)	9.4^{bc}	16.4^{bc}	45.1^{abcd}	4700.0^{abc}
	N_2 (¼-½-¼)	8.8^{bc}	19.2^{a}	55.1^{ab}	3750.0^{bc}
	N_3 (¼-¼-½)	6.7^{c}	17.0^{ab}	46.7^{abc}	3650.0^{bc}
	N_4 (1/3-1/3-1/3)	6.9^{c}	16.1^{bc}	37.5^{bcde}	4100.0^{bc}
LSD (0.05)		7.3	2.3	18.0	2250.0
CV (%)		37.7	8.7	27.3	28.5

Figures in parenthesis indicate the fraction of N applied during sowing, active tillering and panicle initiation of the crop in their order of placement, LSD: Least significant difference, CV: Coefficient of variation. Means sharing the same letter(s) in each column do not differ significantly at 5% p level according to the LSD test

Table 4: Analysis of variance for growth, yield, soil nitrogen and crop tissue N use efficiencies of upland rice on Nitisols at Jimma, 2014-2015

	Mean squares for source of variation			
Parameters studied	V (2)	N (3)	V*N (6)	Error (22)
Days to 50% heading	**	ns	ns	413.80
Days to 90% physiological maturity	ns	ns	ns	1598.20
Plant height (cm)	*	ns	ns	13.90
Tillers/plant (Number)	***	ns	***	17.90
Panicles/plant (Number)	ns	ns	ns	1.20
Panicle length (cm)	***	ns	**	1.90
Fertile spikelets/panicle (Number)	***	ns	**	123.50
Unfertile spikelets/panicle (Number)	*	ns	ns	335.40
Biological yield (kg ha^{-1})	***	ns	**	0.06
Grains yield (kg ha^{-1})	**	ns	*	0.01
Straw yield (kg ha^{-1})	***	ns	**	0.04
1000 grains weight (g)	***	ns	***	0.98
Harvest index (%)	ns	ns	*	26.30
N use efficiency (%)	**	*	ns	38.10
N uptake efficiency (%)	***	*	ns	574.40
N utilization efficiency (%)	*	ns	ns	32.40
N harvest index (%)	ns	ns	ns	53.50
Apparent N recovery (%)	***	*	ns	574.30
Agronomic N use efficiency (%)	***	*	ns	38.10

Figures in parentheses: Degrees of freedom, V: Variety, N: N-timing, Level of significance ns, *, **, ***Denoting non-significant, significant at $p\leq0.05$, at $p\leq0.01$ and at $p\leq0.001$

Table 5: Interaction effect of varieties and N-timings on yield and yield related parameters of rice at Jimma, 2014-2015

Varieties	N-timing	Grains yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Thousand grains weight (g)	Harvest index (%)
Ediget	N$_1$ (½-½-0)	560.0^{bc}	2650.0^{c}	25.10^{a}	18.10^{abc}
	N$_2$ (¼-½-¼)	500.0^{bc}	2100.0^{c}	24.90^{ab}	19.60^{abc}
	N$_3$ (¼-¼-½)	300.0^{bc}	2550.0^{c}	23.20^{bc}	11.70^{c}
	N$_4$ (--)	600.0^{bc}	2150.0^{c}	25.30^{a}	21.50^{ab}
Gumara	N$_1$ (½-½-0)	1100.0^{a}	4700.0^{ab}	20.80^{def}	25.70^{a}
	N$_2$ (¼-½-¼)	1650.0^{ab}	5350.0^{a}	19.80^{ef}	16.90^{bc}
	N$_3$ (¼-¼-½)	700.0^{bc}	4700.0^{ab}	19.50^{f}	12.10^{c}
	N$_4$ (--)	1005.0^{ab}	5350.0^{a}	19.70^{f}	16.00^{bc}
NERICA-4	N$_1$ (½-½-0)	950.0^{bc}	3750.0^{abc}	21.50^{cde}	19.30^{abc}
	N$_2$ (¼-½-¼)	650.0^{bc}	3100.0^{bc}	21.10^{def}	18.60^{abc}
	N$_3$ (¼-¼-½)	950.0^{bc}	2700.0^{c}	21.50^{de}	25.80^{a}
	N$_4$ (1/3-1/3-1/3)	1000.0^{abc}	3100.0^{bc}	21.60^{cd}	21.30^{ab}
LSD (0.05)		700.0	1750.0	1.72	8.68
CV (%)		27.6	27.4	4.50	27.20

Figures in parenthesis indicate the fraction of N applied during sowing, active tillering and panicle initiation of the crop in their order of placement, LSD: Least significant difference, CV: Coefficient of variation. Means sharing the same letter(s) in each column do not differ significantly at 5% p level according to the LSD test

Grain yield and yield related parameters: The analysis of variance showed that grain yield and yield related parameters (biological yield, dry matter, grain and straw yields) were significantly influenced by the interaction effect of varieties and N fertilizer timing treatments. All of them were less sensitive to N fertilizer timing and varieties with no statistical differences between the different N timing treatments and varieties (Table 5). The only exception was Gumara variety which registered relatively better yields although the behaviour was erratic.

In the present experiment, N fertilizer treatments did not influence grain yield and yield related parameters as similar findings were reported by Mae[3] although it was in temperate climate. Rice biological and straw yields are an important resource for livestock feed and construction of houses in Ethiopia[4]. Rice straw yield has great implication for farmers where mixed crop-livestock farming was predominant as it is a means to increase availability of livestock feed. On the other hand, split application of N has been reported to increase rice yield in USA and India[4,6]. However, these studies were conducted for lowland flooded rice.

Marked differences were observed among varieties in their thousand grains weight in which Ediget scored the highest value in all N timing treatments. However, no clear cut variations were observed in Gumara and NERICA-4 varieties. Harvest index was less sensitive to varieties and N fertilizer treatments (Table 5). Thousand grains weight was an important yield determining component and reported to be a genetic character that was influenced least by environmental factors[8].

Seyoum *et al*.[17] reported that HI changes with cultivar and with the environmental conditions. HI is an important plant trait for improving grain yield in cereals. HI values of modern crop cultivars are commonly higher than old traditional cultivars for major field crops[4]. Alcoz *et al*.[8] reported that upland rice yield can be significantly improved with developing genotypes of higher grain harvest index.

Unfertile spikelets/panicle differed significantly between the two study years. Rice varieties had a significant effect on number of unfertile spikelets/panicle over the two years period as a whole (Table 6). The NERICA-4 scored the highest number of unfertile spikelets/panicle followed by Ediget and Gumara. This considerable yearly variation in unfertile spikelets/panicle might be due to the current event of El Nino which was consistently reflected in fluctuations in rice growth and yield parameters.

Table 6: Unfertile spikelets/panicle of upland rice as affected by year and variety at Jimma during 2014 and 2015

Treatments	Unfertile spikelets/panicle (number)
Years	
2014	43.50^{a}
2015	41.90^{b}
LSD (0.05)	1.14
Varieties	
Ediget	42.10^{ab}
Gumara	31.60^{b}
NERICA-4	56.80^{a}
LSD (0.05)	15.61
CV (%)	36.40

Means sharing the same letter(s) in the column do not differ significantly at 5% p level according to the LSD test, CV: Coefficient of variation, ns: Non-significant

Nitrogen uptake, utilization efficiency and their component traits: N use efficiency (NUE) was greater in treatments although differences were non-consistent with respect to varieties and N applications at all growth stages of the crop (Table 7). Ediget was lower in NUE according to the present findings (Table 7). Various genotypes of rice were reported to have different NUE, however, this can also be influenced by environmental and management factors[2]. N uptake efficiency (NUpE) was significantly affected by the main effect of varieties and N timing and splitting (Table 7). All the three varieties differ widely in their NUpE values. However, all the three varieties showed no marked differences in their NUpE while N fertilizer was applied at different stages of growth (Table 7).

The apparent N recovery fraction (ANR) showed significant variations between varieties and N timing treatments although the effect was neither clear nor consistent (Table 7). However, values were considerably higher for Ediget and NERICA-4 but no marked differences among the N timing treatments were observed. As reported by Lopez-Bellido *et al*.[2], higher values of ANR were recorded in lowland rain-fed rice varieties under rain-fed Mediterranean conditions. Agronomic N use efficiency (ANUE) like that of NUpE was significantly affected by varieties and N timing and splitting (Table 7). All the three varieties differ widely in their ANUE values. However, all the three varieties showed no marked differences in their NUpE while N fertilizer was applied at different stages of growth in which NERICA-4 was scored the highest value followed by Ediget and finally Gumara was least in its ANUE value. Except the treatment received N fertilizer applied half during sowing and half during the active tillering stage, all the remaining treatments showed uniform results for ANUE (Table 7).

Table 7: N use efficiency (NUE), N uptake efficiency (NUpE), N utilization efficiency (NUtE), N harvest index (NHI, %), apparent N recovery (ANR, %) and agronomic N use efficiency (ANUE) for upland rice as affected by varieties and split N application at Jimma, 2014-2015

Treatments	NUE	NUpE	NUtE	NHI	ANR	ANUE
Varieties						
Ediget	7.76^{b}	39.38^{c}	20.40^{ab}	31.10	22.30^{b}	7.90^{b}
Gumara	17.38^{a}	99.65^{a}	22.30^{a}	30.40	15.30^{a}	16.70^{a}
NERICA-4	13.75^{a}	61.96^{b}	16.90^{b}	35.80	38.10^{b}	1.40^{c}
LSD (0.05)	5.20	20.30	4.80	Ns	20.30	5.20
N-timing						
N$_1$ (½-½-0)	16.41^{a}	72.65^{a}	22.59	35.83	9.38^{a}	5.20^{a}
N$_2$ (¼-½-¼)	11.89^{ab}	69.16^{ab}	18.66	31.86	12.87^{ab}	9.72^{ab}
N$_3$ (¼-¼-½)	10.04^{b}	57.85^{a}	17.97	28.74	24.18^{a}	11.57^{b}
N$_4$ (1/3-1/3-1/3)	13.51^{ab}	68.33^{a}	20.38	33.32	13.71^{ab}	8.10^{ab}
LSD (0.05)	6.10	23.40	ns	ns	23.40	6.00
CV (%)	17.60	35.80	28.60	22.60	2.50	3.30

Figures in parenthesis indicate the fraction of N applied during sowing, active tillering and panicle initiation of the crop in their order of placement, CV: Coefficient of variation, ns: Von-significant, Means sharing the same letter(s) in the column do not differ significantly at 5% p level according to the LSD test

CONCLUSION

From the study, it has been known that plots treated with N-fertilizer splitted 3 times (1/4th at sowing+1/2 at active tillering stage and the remaining 1/4th at panicle initiation) produced the highest grain and biological yields along with Gumara variety. Therefore, this treatment can be suggested for the farmers in the study area to maximize grain and biological yields and N uptake efficiency and agronomic N use efficiency. Application of N fertilizer to rice preferably as top dressing between active tillering and panicle initiation is a strategy to be recommended from the standpoint of both the environment and of farmer returns.

SIGNIFICANCE STATEMENTS

The efficiency of nitrogen applied to rice crop in satisfying the nitrogen demand depends on the type of fertilizer, timing of application, seasonal trends and others. Hence, decisions regarding nitrogen fertilizer rate and its application date and stage of the crop are among the chief factors that should be considered with great care. This suggests that maximizing nitrogen use efficiency in rice crop is an increasingly important objective in most rice crop management system due to economic and environmental reasons.

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