Optimizing Nitrogen Fertilizer and Seed Rate to the Growth, Yield and Yield Attributes of Rain-Fed Lowland Shaga Rice in Northwestern Ethiopia

Christian Tafere, Habtamu Assega, Zelalem Tadess, and Tilahun Tadesse
Ethiopian Institute of Agricultural Research, Fogera National Rice Research and Training Center
Corresponding author Email: christiantafere03@gmail.com

Abstract

Achieving high yields and quality rice while minimizing environmental impact is crucial for rice production in Ethiopia. However, the absence of specific recommendations for nitrogen (N) fertilizer and seeding rates limits productivity. This study aimed to optimize N fertilizer and seeding rates to enhance the growth and yield of Shaga rice. A factorial combination of three N rates (184, 276, and 368 kg ha^{-1}) and seed rates (60, 80, and 100 kg ha^{-1}) was conducted using a randomized complete block design with three replications. Results indicated that the interaction between N rates and seed rates significantly affected partial factor productivity of nitrogen (PFPn), grain yield, leaf area index, filled spikelets, number of spikelets per panicle, and biomass accumulation. The application of N at a rate of 184 kg ha^{-1} resulted in a 49.2% increase in grain yield. In contrast, higher N rates (368 kg ha^{-1}) led to a decrease in PFPn to 8.4%. Specifically, the combination of an N rate of 184 kg ha^{-1} with a seed rate of 100 kg ha^{-1} yielded 6.7 t ha^{-1} in Fogera, while applying 276 kg N/ha with a seed rate of 60 kg ha^{-1} produced 6.2 t ha^{-1} in North Achefer. Additionally, high N doses delayed physiological maturity and reduced PFPn. Economic analysis revealed that the combinations of N at 184 kg ha^{-1} with a seed rate of 100 kg ha^{-1}, along with N at 276 kg ha^{-1} with a seed rate of 60 kg ha^{-1}, yielded the highest net income returns of 151,456 and 137,811 Birr per hectare in Fogera and North Achefer, respectively. These combinations are recommended as optimal strategies for maximizing profitability in rice production in the two areas.

Key word: *High yield, nitrogen fertilizer, NUE, profitability, seed rate, rice*

Introduction

Rice (*Oryza sativa* L.) is a stable food crop to half of the world's population (Nguyen *et al*., 2018). In Africa, rice is a strategic and priority crop for food security and its consumption is growing faster than any other major commodities. Ethiopia has huge potential accounting for thirty-million-hectare which could be cultivated under different ecosystems in rain-fed low land, upland and irrigated (Hussain *et al*., 2022). Of the potential, 3.7 million hectares of land is suitable for irrigation. Currently, rain-fed lowland rice ecosystem is the major production system by area coverage and production. Globally, the average paddy rice productivity is about 4.6 tons per hectare (FAOSTAT & Agricultural Organization Statistics, 2018). In Ethiopia, the national average yield of rice is only 3.0 tons per hectare, which is below its potential due to inadequate agronomic management practices and terminal moisture stress (Alemu *et al*., 2018). This indicates that yield gains are influenced not only by genetic potential and environmental constraints but also by management practices. Low rice productivity is further exacerbated by biotic and abiotic stresses, poor soil fertility, intensive cropping systems, insufficient and imbalanced fertilizer use, inappropriate planting densities, reliance on local rice varieties, and inadequate management practices (Andrea *et al*., 2022; Baral *et al*., 2020).

In the Ethiopian rice cropping systems, soil fertility depletion and nitrogen deficiency have significant constraint on rice production due to monocropping practices. Particularly, nitrogen is the main yield-limiting nutrient in the Fogera and North Achefer districts rice production system. Applying fertilizers to address nutrient limitations is essential for improving sustainable production. Optimal nitrogen fertilizer application is crucial for plant growth, biomass accumulation, and grain yield. However, excessive use of chemically synthesized nitrogen fertilizers can lead to instability in grain yields and environmental pollution (Chen *et al*., 2014; Ju *et al*., 2015; Zhou *et al*., 2022).

Planting density influences yield by regulating growth patterns, yield components, and photosynthesis traits closely related to crop ideotypes. Both high and low seeding rates significantly affect rice yield and its components (Harris *et al*., 2015). Maximizing seeding rates can lead to non-productive tillers and increased competition for resources, making plants more susceptible to lodging (Garba *et al*., 2015). Nitrogen application rate and seeding rate are two essential factors influencing nitrogen accumulation and dry matter partitioning. Optimizing both nitrogen application rates and seeding rates is necessary for coordinating balanced crop growth and maximizing yield potential while efficiently utilizing resources (Tang *et al*., 2020). The combination of nitrogen levels and seeding rates offers multiple advantages in regulating growth and enhancing yields. Proper nitrogen fertilizer application rates alongside optimal seeding rates improve growth outcomes while reducing resource waste and environmental pollution (Aslam *et al*., 2002; Liang *et al*., 2013).

Nitrogen rate and seeding rate play crucial roles in leaf area index and thus in the interception of photosynthetically active radiation. Increasing nitrogen levels while decreasing seeding rates enhances net photosynthetic rates, stomatal conductance, chlorophyll content, and metabolic enzyme activity (Hemat *et al*., 2022). However, research on optimizing the combination of seeding rates and nitrogen fertilizer is limited in North Achefer and Fogera districts in Ethiopia. Therefore, this study aims to evaluate strategies for optimizing nitrogen fertilizer application and seed rate for directly seeded Shaga rice to improve both yield and its components in Ethiopia. The hypothesis posits that reducing nitrogen rates while increasing seed rates for dry-seeded Shaga rice could effectively enhance yield components and improve nitrogen use efficiency in rice production systems.

Materials and Methods

Description of the Study Area

The study was conducted in the Fogera and North Achefer districts of Ethiopia, located 56.7 km and 101 km from Bahir Dar (the capital city of the Amhara Regional State) and 615 km and 591 km from Addis Ababa (the capital city of Ethiopia), respectively (Fig.1). A field experiments was conducetd for two consecutive years during the main rainy season (June to October) of 2021 and 2022. The Fogera experimental site is geographically situated at 13°19' North latitude and 37°03' East longitude, with an altitude of 1,800 meters above sea level (Tilahun *et al*., 2013; Amare *et al*., 2019). In contrast, North Achefer is located at altitudes ranging from 1,500 to 2,500 meters above sea level. The climatic conditions of the Fogera plain is featured with mean annual minimum, maximum, and average temperatures of 14.0 °C, 27.7 °C, and 20.8 °C, respectively. While the mean annual minimum, maximum, and average temperatures of the North Achefer testing site were 15.3°C, 24.3°C and 19.8 °C, respectively. The mean annual rainfall in the districts range from 1,450 to 1,594 mm (Bayuh Belay & Melaku Wale, 2019). Rainfall in both areas is uni-modal, typically occurring from June to October, with an average annual total of 1,363.7 mm over many years. The total rain-fall, minimum and maximum temperature of Fogera and North Achefer are presented in Figure 2 & 3 and Figure 4&5 respectively.

The soil type in Fogera and North Achefer is vertisol. Analysis of soil physicochemical properties of the study sites (Fogera and North Achefer) are shown in Table 1. Excessive application of N fertilizer adversely influences soil pH, organic carbon (OC), organic matter (OM), available phosphorous (P), total nitrogen (N), electric conductivity (EC), and cation exchange capacity (CEC) properties, consequently decreasing the yield. A decrease in soil pH and an increase in soil OM, total N, and total carbon concentration were observed with long-term N fertilization. The pH of the experimental site soil was slightly acidic and was preferred for rice crops. The total N content (0.12%) was within the range of low levels which is 0.02-0.5% for tropical soils. Organic matter (2.07%) of the soil was medium under the range (2-4%) for Ethiopian soils as to the criteria developed by Murphy (1968). Soil organic matter is essential for water-stable aggregates, and bulk density influences soil air permeability and soil water, which affects the growth and development of crops (Rienzi, E. A. 2016). The experimental sites had 6.5 ppm for available P content and found in a range of deficiency (20-40 mg kg-1) for most crops (Landon, 1991). The CEC of the soil was 55.4 Cmolg-1 and 56.4 Cmolg-1 for the Fogera and North Achefer sites, respectively.

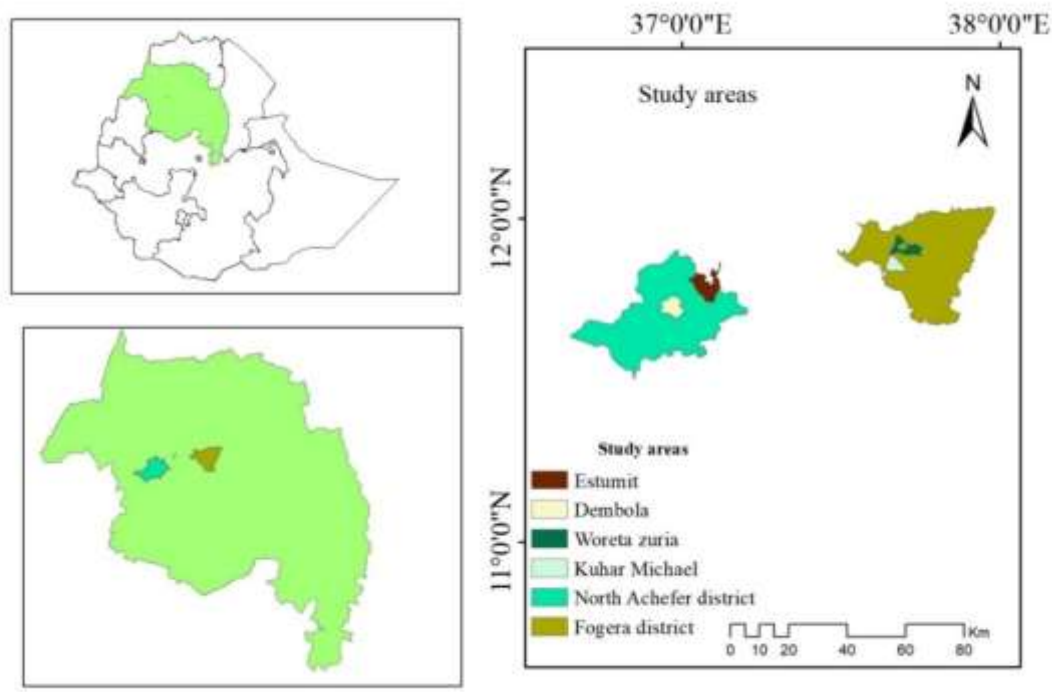

Figure 1 Map of the study area

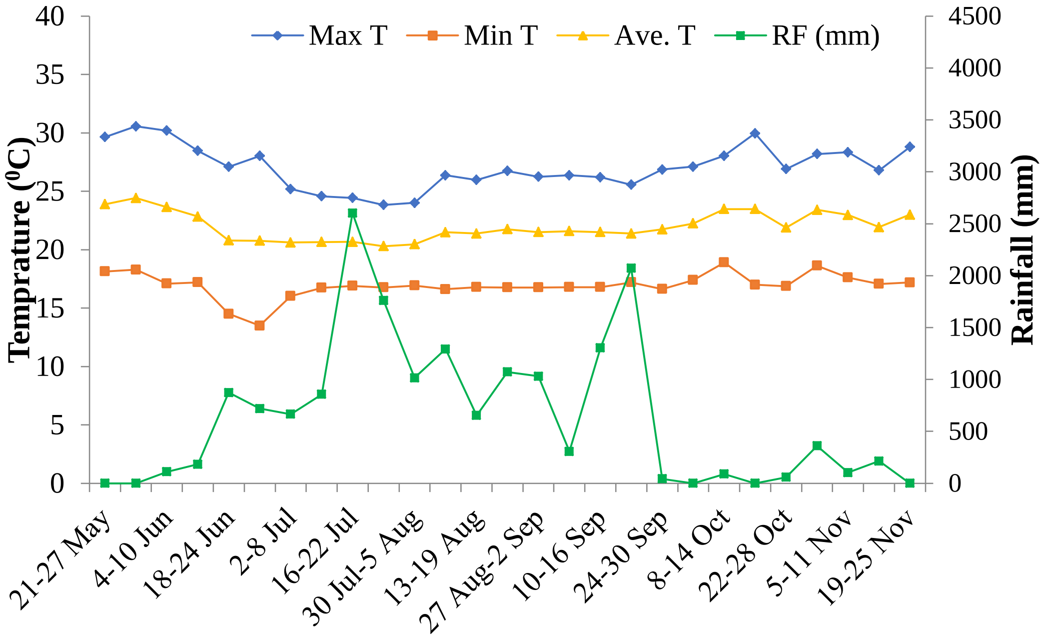

Figure 2: Rainfall (RF), maximum temperature (T max), minimum temperature (T min) and average temperature (Ave. T) of Fogera experimental site for the 1st growing season (2020-2021)

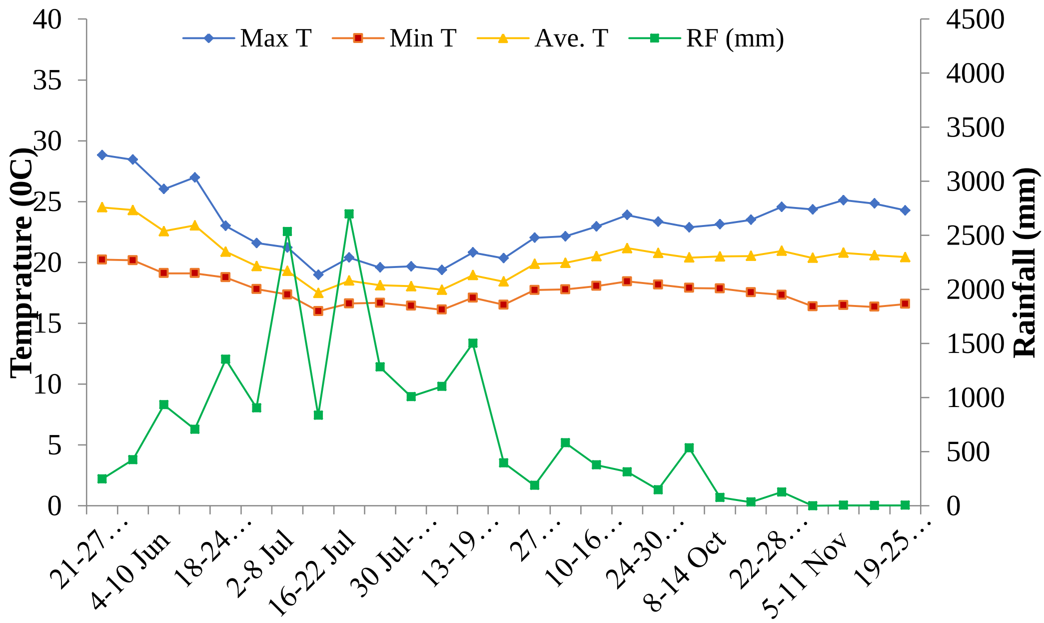

Figure 3. Rainfall (RF), maximum temperature (T max), minimum temperature (T min) and average temperature (Ave. T) of Fogera experimental site for the 2nd growing season (2021-2022)

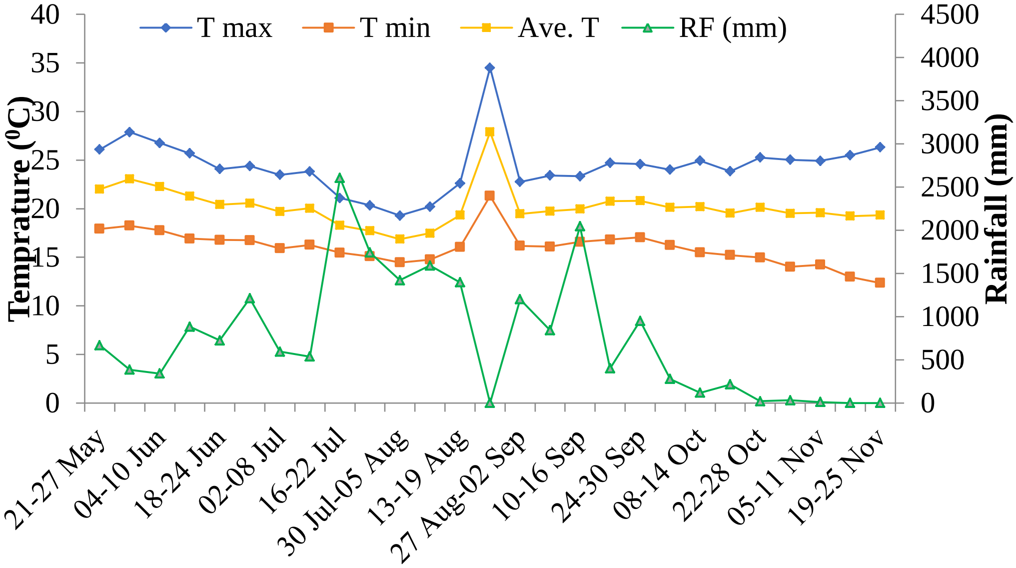

Figure 4. Rainfall (RF), maximum temperature (T max), minimum temperature (T min) and average temperature (Ave.T) of North Achefer experimental site for the 1st growing season (2020-2021)

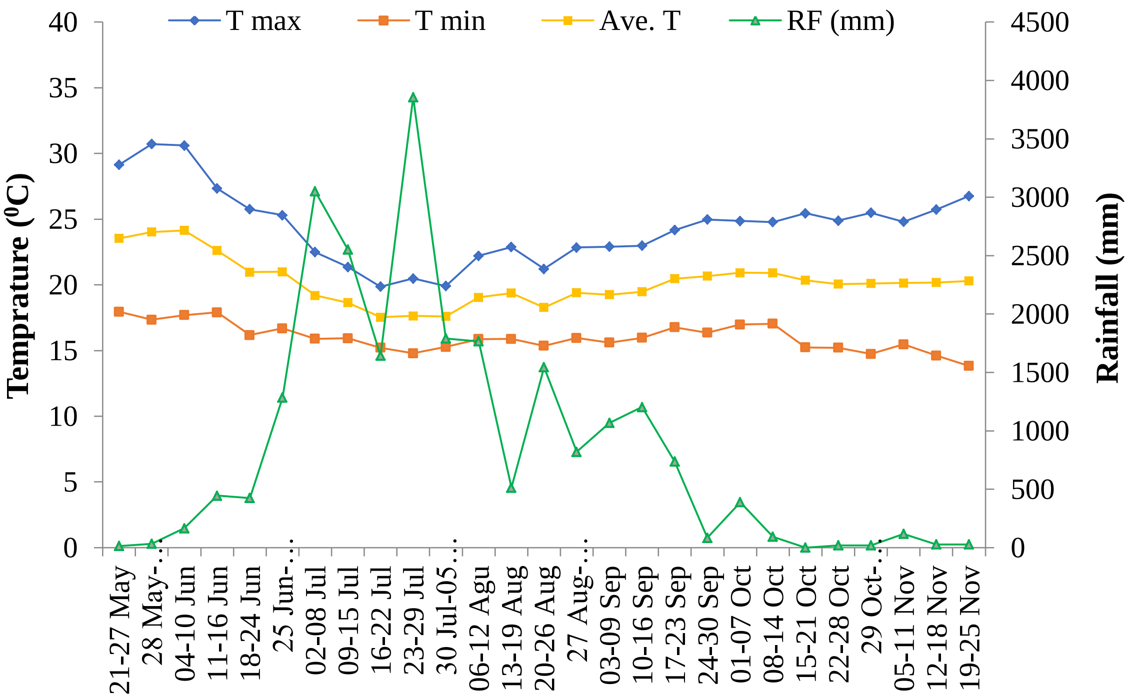

Figure 5. Rainfall (RF), maximum temperature (T max), minimum temperature (T min) and average temperature (Ave. T) of North Achefer experimental site for the 2nd growing season (2021-2022)

Table 1: Soil physicochemical characteristics of the study area (rice field) before planting

Soil properties	Fogera	North Achefer	Units
pH (H_2O)	5.9	5.6	-
Total nitrogen (TN)	0.1	0.1	%
Organic carbon (OC)	1.2	1.2	%
Organic matter (OM)	2.1	2.1	%
Available phosphorus (P)	6.5	6.5	ppm
Electrical conductivity (EC)	0.5	0.5	ds/m
Cation exchange capacity (CEC)	55.4	56.4	C/molg

Experimental design, Testing material and Treatments

A factorial combination of three N rates (184, 276 and 368 kg ha^{-1}) and three seeding rates (60, 80 and 100 kg ha^{-1}) was laid out in a randomized complete block design with three replications. The gross plot size of the experiment was 3m x 4m consisting of 15 rows spaced at 20cm between rows, using direct seeding planting method. The net plot area was made by excluding the left and right outer rows and a plot length of 0.5 m from the top and bottom sides of the plot and the final net plot size was 2m by 3m. The rain-fed lowland Shaga rice variety was used as a planting material. The variety was selected based on wide adaptability to the agro-ecological conditions and unique morpho-physiological characteristics compared with other rice varieties. All plots were treated with uniform P_2O_5 rates of 46kgha^{-1} from NPS source and applied once at planting. NPS fertilizer (19% of N, 38% of P_2O_5, 7% of S) was used as P_2O_5 and N fertilizer source and Urea fertilizer (46% N) was used as a source of nitrogen.

Data Collection

Phenological traits days to heading were estimated as several days from sowing to 50% of the plants bear heading, days to flowering, the number of days from sowing to 90% of the plants flowered, days to maturity from the date of sowing to 90% of the plants physiologically matured. Growth and yield parameters such as plant height, culm length, filled and unfilled spikelets per panicle were measured from five plants per plot, tiller number per row meter length, panicle number per row meter length, biomass yield, straw yield, grain yield, thousands grain weight, harvest index were collected from the net plot areas following their respective standard measuring methods and procedures. Leaf area index was calculated LAI calculator by taking photo in the field. The grain yield and thousand seeds weight were adjusted at 14% standard moisture content.

$$\text{Wf} = Wix\,\frac{100-MCi}{100-\text{MCf}} \text{ ------------------(1)}$$

Where, Wf = final weight (g), Wi =initial weight (g) MCi= Initial moisture content (%), MCf = Moisture content final (14%).

Harvested index (%) = $\frac{\text{Grain yield}}{Biological\ yield} x100$---------------------------------(2)

Partial factor productivity of nitrogen

Nitrogen use efficiency is the yield per unit of nitrogen applied and the N partial factor productivity, which integrates fertilizer inputs. PFP_N corresponds to the yield obtained with the application of N fertilizer.

$PFP_N = \frac{\text{Grain yield with n application}}{\text{N application rate}} * 100$------------------------------(3)

Statistical Analysis

The combined analysis was performed for the two consecutive years in 2020-2021 and 2021-2022 cropping season. Least significance difference (LSD) at 1% and 5% was used to discriminate factors studied seed rate, N rate and combinations between seed rate and N fertilization for each trait. The data was analyzed using SAS software, version 9.2 and a two-way analysis was used to compare the effects of main and interaction effects of seed rate and nitrogen fertilizer application rate.

Partial Budget Analysis

A partial budget analysis was conducted using CIMMYT's methodology (1988) to evaluate the economic viability of nitrogen (N) fertilizer rates and seed rates, focusing on gross benefits (GB), total variable costs (TVC), net benefits (NB), and marginal rate of return (MRR %). This analysis included partial budgeting, dominance, and MRR analysis to assess economic viability. Economic values were estimated based on the average market price of rice grain in Woreta during the 2020-2021 and 2021-2022 seasons. The partial budget analysis organized experimental data alongside survey information regarding costs and benefits. Variable costs included N fertilizer, seed rates, labor, and transportation, all calculated per hectare in Ethiopian Birr (ETB). Gross benefit per hectare was determined by multiplying the local rice price by the grain yield for each treatment. The net benefit for each treatment was calculated as the difference between gross benefit and variable costs. The MRR % was derived from the ratio of the difference in net benefits to the difference in variable costs across treatments. Economic analysis accounted for all variable costs, focusing on input and output costs during the 2020-2021 and 2021-2022 periods. The cost of urea fertilizer was approximately 27.9 Birr per kg, while rice grain and straw prices were 24.024 and 2.016 Birr per kg, respectively.

Results and Discussion

Due to the variations of the two sites, the results of Fogera and North

Achefer are presented separately as follows.

Results of Fogera Experimental Site

Phenology of Shaga Rice

Results of combined analysis of variance indicate that the main effect of N fertilizer rate and seeding rate significantly influenced days to heading. The combination of N rate and seed rate was found in different heading dates. Increasing nitrogen fertilizer rate extended days required for 50% heading across all increased seed rate. The present result is inconsistent with Muhammad *et al*. (2016) who stated that under increased rates of N fertilizer rate supply in wheat, plants delayed heading days than low-level supply of nutrients. The heading date differs with in a plant and among plants in the same filed. The date of heading was prolonged as the N rate was increased. Regarding to combined effects of N fertilizer rate and seed rate, 50% heading date was earlier for the combination of $N_{\mathbf{184}}$+$SR_{\mathbf{100}}$ kg ha^{-1} (93 days) followed by the combination $SR_{\mathbf{80}}$+$N_{\mathbf{184}}$ kg ha^{-1} (96 days) while a late heading date was produced in the combined application of $N_{\mathbf{368}}$+$SR_{\mathbf{100}}$ kg ha^{-1} (102 days) (Table 2). Therefore, the most prolonged duration to reach 50% heading was observed under the combined effects of $SR_{\mathbf{100}}$+$N_{\mathbf{368}}$ kg ha^{-1}. The present result was in agreement with the results of Mulatu and Grando (2011) who stated that days to 50% heading was significantly delayed by higher density and nitrogen fertilizer rates combination compared to the highest seed rate by increasing N levels from low-level on the production of food barely.

Table 2: Effects of N application and seed rate on phenological response in Fogera study site in 2021-2022 cropping season

SR kg ha^{-1}	N kg ha^{-1}	50% HD	90% FD	DH	HDD	HaDD
	184	95.0	100.0	148.0	-	-
60	**276**	99.0	106.0	157.0	4.0	9.0
	368	101.0	109.0	157.0	6.0	9.0
	184	96.0	102.0	148.0	2.0	0.0
80	**276**	101.0	108.0	157.0	6.0	9.0
	368	100.0	108.0	157.0	6.0	9.0
	184	93.0	98.0	148.0	-2.0	0.0
100	**276**	100.0	107.0	157.0	5.0	9.0
	368	102.0	110.0	157.0	8.0	9.0

Where SR= Seed rate, N= Nitrogen fertilizer rate, HD=heading date, FD= flowering date, DH= days to harvest, HDD= heading date difference, HaDD=harvesting date difference

Effective Panicle and Panicle Length

Effective panicles and panicle length were highly significantly ($P<0.01$) influenced by the N rates but not by the main effects of SR and the combination of the two factors. The tallest panicle length (17.9cm) among N fertilizer rates was found with the application of 368 N kg ha^{-1}. Anny (2021) reported that significantly longer panicle length was found from the application of 320 kg ha^{-1} N for experiments conducted for consecutive two years and statistically similar to the application of 80 and 120 kg ha^{-1} N. However, the shortest panicle length (15.9cm) was observed with the application of 184 N kg ha^{-1} and statistically similar with the application 276 N kg ha^{-1} fertilizer rate. The highest number of effective panicles per row meter length was obtained at the lowest rate of 184 N while the lowest was exhibited at the highest rate of 368 N and statistically alike with 276 N kg ha^{-1}. In confirming this result Chang et al., 2022 reported that in high soil fertility increasing nitrogen topdressing from 20% to 40% hinders tillering ability and decreases the effective panicle number (Table 3).

Filled Spikelet and Number of Spikelets per Panicle

The main factor seed rate (SR) and combination with N significantly influenced filled spikelets per panicle however; N fertilizer did not significantly influence filled spikelets per panicle. The highest number of filled spikelets per panicle (108.9) was exhibited at the SR of 60 kg ha^{-1} while the lowest number of filled spikelets per panicle (93.0) was obtained at the highest SR of 100 kg ha^{-1}. The filled spikelets per panicle were statistically alike at SRs 60 and 80 but decreased at the SR of 100 kg ha^{-1}. The higher the planting density, the higher the effective panicle number but the lower the number of spikelets per panicle and the seed setting rate (Tang, J. C *et al.*, 2020). Regarding to the interaction effects, the highest number of filled spikelets per panicle (119.9) was attained with the combination of $SR_{100}+N_{184}$ kg ha^{-1} and statistically alike with combined effects of $SR_{60}+N_{184}$, $SR_{60}+N_{276}$, $SR_{60}+N_{368}$ (Table 3). Tang J.C (2020) also reported that the best yield performance was achieved in the application of N190 kg ha^{-1} and the seeding rate of 25 kg ha^{-1} combinations may have been due to the high effective panicle number and consistence response of other yield components. However, the lowest number of filled spikelets per panicle was found at the combination of N fertilizer rate (N_{368} kg ha^{-1}) along with the seeding rate (SR_{100} kg ha^{-1}). This indicates that filled spikelet per panicle was increased with the decrease of N rates. The decrease in filled spikelets per panicle as the N rate increased might be due to a higher number of tillers per plant and prolonged maturity.

Dry Biomass Accumulation

Dry biomass accumulation was significantly ($P<0.01$) influenced by N fertilizer rates but not by the main effects of SR. However, the combination of the two factors affected the dry biomass accumulation of Shaga rice. The highest biomass yield (23.2 t ha^{-1}) was found with the application of $N_{\mathbf{368}}$ kg ha^{-1}. In line with the current finding, Olga *et al*., (2022) stated that N fertilizer applied to wheat plants tends to improve the rate of photosynthesis and increase canopy biomass and grain yield. However, the lowest biomass yield was attained with the application of $N_{\mathbf{184}}$ kg ha^{-1}. Dry matter accumulation of shoot and root per plant is significantly influenced by N fertilizer rate (Jun Qiao *et al*., 2013). Combined application of N fertilizer rate and seed rate was found to have significant effect on dry biomass. The highest biomass accumulation was obtained at the combination of $N_{\mathbf{368}}+SR_{\mathbf{60}}$ kg ha^{-1} but statically equivalent with the combined application of $N_{\mathbf{276}}+SR_{\mathbf{100}}$, $N_{\mathbf{278}}+SR_{\mathbf{80}}$, $N_{\mathbf{368}}+SR_{\mathbf{100}}$ kg ha^{-1} (Table 3). This might be due to the rate of biomass production which is determined by the rate of canopy photosynthesis. Short duration and maximum rate of biomass accumulation were achieved in direct-seeded rice and this biomass determines the crop yield by determining the crop photosynthesis and biomass accumulation (Kumar *et al*., 2006). However, the straw yield was not significantly affected by the main effects of N application rate and seed rate. The combined effects of N rate and SR did not also significantly influence the straw yield of Shaga rice.

Grain Yield

Results of analysis of variance indicated that grain yield was highly significantly ($P<0.01$) influenced by main effects of nitrogen rate (N) and significantly ($P<0.05$) affected by the combinations of SR and N rate but not by the main effects of SR (Fig. 6a). The highest grain yield (6.3t ha^{-1}) was achieved at the lowest application rate of $N_{\mathbf{184}}$ kg ha^{-1} while the lowest grain yield (3.1t ha^{-1}) was found at the highest application rate $N_{\mathbf{368}}$ kg ha^{-1} (Fig. 6b). The grain yield 6.3 to 5.3 and 3.1 t ha^{-1} were highly significantly ($P<0.01$) decreased as the N application rate increased from $N_{\mathbf{184}}$ to $N_{\mathbf{276}}$ and $N_{\mathbf{368}}$ kg ha^{-1} respectively. Under the same planting density increasing N application rate was not valuable for nitrogen uptake in super high-yielding rice (Xian-qing *et al*., 2009). Applying N fertilizer rates $N_{\mathbf{276}}$ & $N_{\mathbf{368}}$ kg ha^{-1} over $N_{\mathbf{184}}$ kg ha^{-1} reduced the grain yield by 15.9% & 50.8% respectively. Nitrogen is the most important nutrient in rice production because its deficiency or excess induces grain yield reduction. Fertilizer application results in increased yield with diminishing returns until maximum yield is reached and thereafter, excessive fertilizer application can reduce yield. Yield response to fertilization varies with crop, soil type and other limiting factors (Jessica, 1999).

Regarding the combined effects of N application rate and SR grain yield was significantly ($P<0.05$) influenced. The highest grain yield (6.7 t ha^{-1}) was exhibited with the combined application of N_{184}+SR_{100} but the grain yields of 6.3 and 5.9 t ha^{-1} were not significantly different ($P<0.05$) with the combined application of N_{184}+SR_{60} and N_{184}+SR_{80} kgha^{-1} respectively (Fig. 6c). Grain yield highly relies on variety, and agronomic practices, particularly on planting density and N fertilization (Joseph *et al*., 2021). The grain yield was higher and achieved at the combination of SR_{100}+N_{184} kg $ha^{-1}$and numerous studies in line with this finding demonstrated that a grain yield increase could be achieved through either a harvest index improvement or aboveground biomass, LAI, filled grain number per panicles and plant height enhancement (Zhang, *et al*., 2017). On contrast, thousand-grain weights were believed the most important yield component and were not influenced by the main effects of N & SR as well as the combination of SR and N rates as shown in Table 3.

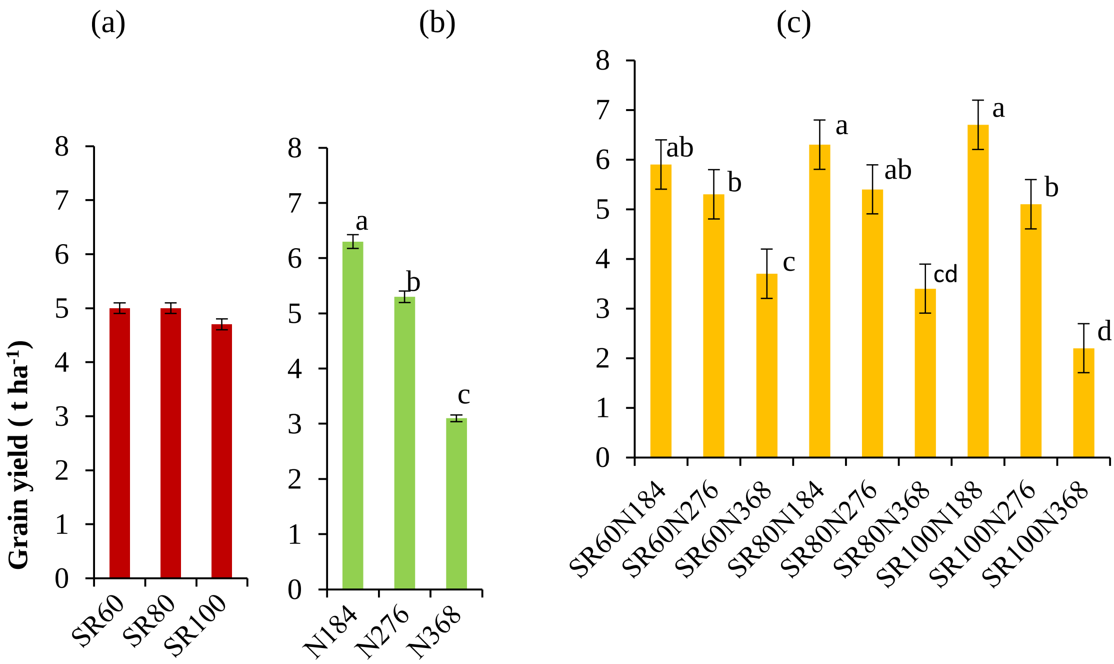

Figure 6. Influence of seed rate (a), N fertilizer (b), and interaction of SR and N fertilizer (c) on the grain yield of Shaga rice in the Fogera study site 2020-2021 and 2021-2022 cropping season

Harvest Index

Harvest index was significantly ($P<0.01$) affected by the N application rate and significantly ($P<0.05$) influenced by the two factors combination but not by the main effects of SR. The highest harvest index was attained from the application of N_{184} (37.2%) followed by the application of N_{276} (24.4%) kgha^{-1} while the lowest was found in the application rate N_{368} (15.1%). This might be due to the higher the harvest index value, the greater the physiological potential of the crop to convert dry matter to grain yield. Combined effects of $SR_{100}+N_{184}$, $SR_{80}+N_{184}$, $SR_{60}+N_{184}$ obtained the highest harvest index 38.2%, 36.0%, & 37.3% respectively and statistically alike. This might be the partitioning of total nitrogen content more to the vegetative part of the crop than the grain and increased above-ground biomass with the application of nitrogen. Harvest index decreased as the SR and N interaction increased while the positive effect on HI at the low rate of N fertilizer may have been due to the attributes of a positive effect on biomass partitioning to grain yield. The lowest harvest index was produced from the interaction effects of $SR_{100}+N_{368}$ (12.3%), $SR_{80}+N_{368}$ (17.1%) and $SR_{60}+N_{368}$ (17.1%) (Table 3). This result is in agreement with the finding of Singh (2002) who reported that increased seeding rate at optimum and increased N rate increase harvest index and the capacity of a crop to convert the dry matter in to economic yield is indicated by its harvest index. The decrease in HI at the higher rate of N fertilizer application might be ascribed to greater vegetative biomass yield production compared to the grain yield and proportionally higher vegetative biomass yield than the grain yield at higher N application rate. This finding is in line with the result of Woyema *et al.*, (2012) which reported the highest HI from the lowest rate of N fertilizer application.

Plant Height

Plant height was highly significantly ($P<0.01$) influenced by N rates and a combination of SR and N rates. However, the main effect of SR did not significantly influence plant height. The tallest plant height was found from the highest N application rate (N_{368}) kg ha^{-1} while the shortest plant height was recorded from the lowest rate N_{184} kg ha^{-1}. The application of fertilizer N_{368} and N_{276} kg ha^{-1} increased the plant height by 13.6% and 4.0% respectively. This increment in plant height might be that N fertilizer improves the synthesis of macromolecules and photosynthesis rate on cell division, cell elongation and length of internode. In line with the present result Mboyerwa *et al.*, (2022) reported that plant height increased with the increase in amount of nitrogen application and slightly decreased in the later stage of harvest. Regarding the combined effects, the tallest plant height 127.5cm, 126.3cm, 124.7cm and 124.0cm was obtained at

$SR_{100}+N_{368}$, $SR_{60}+N_{368}$, $SR_{80}+N_{368}$ and $SR_{100}+N_{276}$ kg ha^{-1} combination respectively whereas the shortest plant height was exhibited from the combination of $SR_{100}+N_{184}$ (108.0cm), $SR_{100}+N_{184}$ (109.3cm) and $SR_{100}+N_{184}$ kg ha^{-1} (109.7cm (Table 3). These might be due to the attributed effect of increasing the supply of nitrogen nutrients which helped in high vegetative growth and development. Similar to the present result Shahraki *et al*. (2017) stated that plant height of durum wheat was significantly influenced by nitrogen rate and the tallest plant height was found in response to the highest N fertilizer supply whereas the shortest plant height was produced from the control. Excessive plant population can lead to greater plant height and weaker stalks, increasing the potential for losses due to lodging and disease (Dofing and Knight, 1994).

Culm Length

Culm length was significantly (P<0.01) influenced by N rates and the combination of SR and N rates but not by main effects of SR. The longest culm length was recorded from plants treated with the highest rate of N_{368} kg ha^{-1} whereas the shortest culm length was produced at the lowest rate of N_{184} kg ha^{-1} (Fig. 7). However, statistically, it was not significantly different from the rate N_{276} $kgha^{-1}$. The moment of the aerial part is not affected by the planting density because of the decrease in culm length and increase of culm weight with the decrease in seeding rate (Hiromi and Taiichiro, 2020). The effect of seeding rate on culm length inferred that low transmission of solar radiation into the canopy for high seeding rate crops. Culm length was highly significantly (P<0.01) increased with the increase of nitrogen rate. Considering the combined effects, the culm length was highly significantly (P<0.01) influenced by the combination of SR & N rates. The highest culm length was exhibited at the interaction effects of $SR_{100}+N_{368}$ and statistically alike with the combination of $SR_{60}+N_{368}$, $SR_{80}+N_{368}$ and $SR_{100}+N_{276}$.

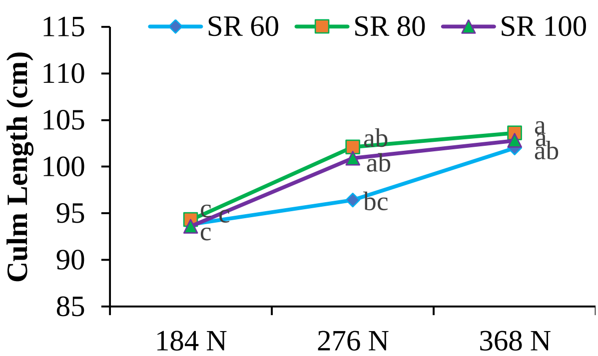

Figure 7. Effects of seed rate and N application rate interaction on the culm length of Shaga rice in Fogera study sites 2021-2022 cropping season

Culm length was highly significantly increased with the increased rates of N fertilizer. Increasing the N rates lowers stem strength and increases lodging index. These may cause to creation of longer elongated basal internodes responsible for higher plant height and higher lodging index. The higher lodging of rice plants is primarily attributed to the weak breaking strength of lower internodes (Zhang *et al.*, 2016). However, growth characteristics, and tiller number per row meter length were not significantly influenced by the main effects of N fertilizer rate and SR. The combined effects of both factors also did not significantly influence the total tiller number per meter row length.

Table 3: Combined main and interaction effects of seed rate (SR) and N rates on the growth, yield and yield attributes of Shaga rice in Fogera study site 2020-2021 and 2021-2022 cropping season.

SR (kg ha^{-1})		PH (cm)	ET (No)	PL (cm)	FS (No)	FP (No)	DB (t ha^{1})	TGW (g)	SY (t ha^{-1})	HI (%)
	60	118.1	95.4	17.1	108.9a	93.8	20.7	25.4	15.7	26.7
	80	118.4	95.7	17.3	107.6a	94.3	21.3	26.0	16.3	25.9
	100	119.8	101.3	17.3	93.0b	99.3	21.6	27.1	17.0	24.1
N (kg ha^{-1})										
	184	109.0c	98.5	15.9b	104.9	106.9a	16.4c	26.4	11.1c	37.2
	276	121.2b	96.2	16.9b	107.0	96.3b	19.1b	26.0	17.8	24.4
	368	126.2a	97.8	17.9a	97.6	94.1b	23.2a	26.1	20.1a	15.1
SR*N (kg ha^{-1})										
60	184	109.7c	92.2	16.8	108.9ab	91.0	16.2c	25.9	10.3	37.3a
	276	118.4b	96.3	16.7	110.6ab	93.8	21.9ab	26.4	16.5	25.5b
	368	126.3a	97.7	17.7	107.3ab	96.5	24.1a	23.7	20.4	17.1c
80	184	109.3c	96.5	16.8	106.0abc	94.7	17.9bc	26.7	11.6	36.0a
	276	121.1ab	95.5	17.1	108.2ab	94.2	23.6a	25.5	18.2	24.7b
	368	124.7ab	95.2	18.0	99.9c	94.0	22.5ab	26.0	19.1	17.1c
100	184	108.0c	106.8	17.1	119.9a	105.2	18.1b	26.6	11.4	38.2a
	276	124.0ab	96.7	16.8	102.3b	94.3	23.8a	26.1	18.7	23.0b
	368	127.5a	100.5	18.1	76.9d	98.3	23.0a	28.6	20.8	12.3d
CV (%)		5.8	14.0	5.3	18.6	13.9	11.7	11.0	18.0	13.4

Note: SR= Seed rate, N= Nitrogen rate, PH=Plant height, ET=Total tiller per row meter length, CL=Culm length, PL=Panicle length, FG=Filled spikelet number per panicle, FP=Fertile panicle per row meter length, DB= Dry biomass, GY=Grain Yield, TGW= Thousand grain weight, SY=Straw yield, HI=Harvest index

Physiological Traits

Leaf Area Indices

The Leaf Area Index was significantly (P<0.05) influenced by the main effects of N rates but not by the main effects of SR. A higher value of leaf area index (5.5) was attained with the application of N_{276} kg ha^{-1} whereas the lowest leaf area index (2.7) was found at the lowest application rate of N_{184} kg ha^{-1} (Fig. 8). Apt leaf area index might be maintained with a relatively high N rate and seed rate (Hou *et al*., 2019).

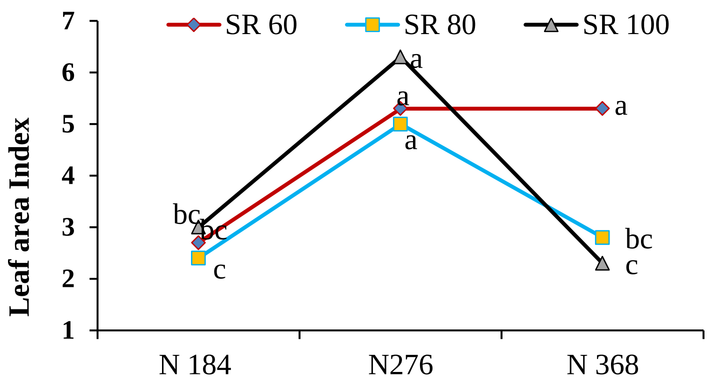

Figure 8. Influence of seed rate and N fertilizer interaction on the leaf area indices of Shaga rice in Fogera study site 2021-2022 cropping season

The combination of N rate and SR were highly significantly (P<0.01) influenced LAI. The maximum leaf area index (6.3) was attained $SR_{100}+N_{276}$ kg ha^{-1} combination whereas the minimum leaf area index (2.3) was found $SR_{100}+N_{368}$ kg ha^{-1} combination and statistically at par with the combination of $SR_{60}+N_{184}$, $SR_{80}+N_{184}$, $SR_{100}+N_{184}$ kg ha^{-1}. However, the leaf area index was steadily increased by the interaction effects of $SR_{60}+N_{276}$, $SR_{80}+N_{276}$ & $SR_{100}+N_{276}$ kg ha^{-1}. Nitrogen level and seed rate increased the leaf area index and the increased leaf area index increased light interception and photosynthesis. Crop management practices such as fertilizer application and seeding rate are used to optimize canopy photosynthesis and yield, mainly by controlling LAI (Peng, 2000). As the N level increased from N_{184} to N_{276} kg ha^{-1} the leaf area index was increased but decreased N_{368} kg ha^{-1} application rate. However, the leaf area index increased when the seeding rate was increased from SR_{60} to SR_{100} kg ha^{-1}. This result is in line with the finding of Zhao *et al*., 2009 increasing seeding rate and fertilizer rates significantly increased leaf area indices and dry biomass.

Partial Factor Productivity nitrogen (PFPn)

Partial factor productivity of nitrogen (PFP_N) decrease as the rate of N fertilizer application increases (Table 4). Appropriate N fertilizer application significantly improved nitrogen use efficiency of direct-seeded Shaga rice. High-yielding due to high efficiency of N fertilizer application achieved

34.2 kg kg^{-1} of higher N partial factor productivity while low yielding low efficiency 8.4 kg ka^{-1} was produced at the higher nitrogen fertilizer application. Xie *et al*., 2020 found out a survey result on the farmer's field indicated that rice yield and partial factor productivity of applied N averaged 8273 kg ha^{-1} and 23.1 kg kg^{-1} in regional-scale with 21-43% & 33-52% potential increases respectively. Nitrogen use efficiency of Shaga rice with the application of a high rate of N is relatively low due to the loss of applied N through volatilization, denitrification and leaching which requires nitrogen fertilizer management to reduce environmental pollution and enhance N fertilizer economic benefit. The low partial factor productivity with the application of the highest N rates in the present study shows that attention should be given to improving the nitrogen partial factor productivity through split application, slow-release N fertilizer and time of application to minimize the loss of N in flooded plain. Cassman *et al*., 1996 found that partial factor productivity is the broadest procedure of NUE by integrating fertilizer input and inherent soil N supply capacity and the yield achieved.

Table 4: Partial factor productivity of nitrogen

N kg ha^{-1}	Grain Yield kg ha^{-1}	PFPn (kg kg^{-1})
184	6300.0	34.2
276	5300.0	19.2
368	3100.0	8.4

Economic Return

The economic analysis was computed to assess the economic viability of N fertilizer rate and seeding rate on a data found 2020-2021 and 2021-2022 cropping season and presented in Table 5. The economic analysis revealed the optimum seed rate and N application was important because it gave the highest net economic benefit. The NB for the combination of $SR_{100}+N_{184}$ kg ha^{-1} increased with the use of inputs. For the treatment combination $SR_{100}+N_{184}$ kg ha^{-1} increased net benefit with respective to the values of 151,456 Birr ha^{-1} and acceptable level of MRR (≥100 %). Results show that the treatment combinations $SR_{100}+N_{184}$ kg ha^{-1} is more profitable in terms net benefit and MRR than the combination of $SR_{80}+N_{184}$ kg ha^{-1} with respect to the values of 143,739 Birr ha^{-1} and MRR 1864.107 (Table 5).

Table 5: The Economic analysis for Shaga rice yield as affected by N application rate and SR in Fogera experimental site

SR (kg/ha)	N (kg/ha)	TVC (Birr/ha)	GY (t/ha)	SY (t/ha)	AGY (t/ha)	ASY (t/ha)	GB (Birr/ha)	NB (Birr/ha)	Dominance	MRR %
60	184	12828	5.9	10.3	5.3	9.3	146128	133300		
80	184	13388	6.3	11.6	5.7	10.4	157127	143739		1864.107
100	184	13948	6.7	11.4	6	10.3	165404	151456		1378.036
60	276	18402	5.3	16.5	4.8	14.9	144417	126015	D	
80	276	18962	5.4	18.2	4.9	16.4	149662	130700	D	
100	276	19522	5.1	18.7	4.6	16.8	144089	124567	D	
60	368	23976	3.7	20.4	3.3	18.4	116933	92957	D	
80	368	24536	3.4	19.1	3.1	17.2	108095	83559	D	
100	368	25096	2.2	20.8	2	18.7	85259	60163	D	

Where SR= Seed rate, N= Nitrogen fertilizer rate, TVC=total variable cost, GY=grain yield, SY=straw yield, AGY=Adjusted grain yield, ASY= Adjusted straw yield, GB=gross benefit, NB= net benefit, MRR= Marginal rate of return

Results of North Achefer Study Area

Plant Height

Plant height was highly significantly ($P<0.01$) affected by N rates and significantly ($P<0.05$) influenced by interaction effects but not by the main effects of SR (Table 6). The tallest plant height was recorded at N_{368} kg ha^{-1} application while the shortest plant height was found at N_{184} kg ha^{-1}. This finding is in agreement with the study by Khan (2000), reported that increasing nitrogen rates increased plant height by stimulating cell division and elongation as well as root growth and dry matter content of rice plants. The supply of N fertilizer at N_{368} and N_{276} kg ha^{-1} increased plant height by 8.6% and 2.6% respectively, compared to the low-rate nitrogen supply. Increased rates of N applied to the soil increase internode length which ultimately resulted in increased plant height and overall vegetative growth of bread wheat enhanced by the application of N fertilizer (Saeed *et al*., 2012). Regarding the combined effects tallest plant height was attained at SR_{80}+N_{368} kg ha^{-1} combination and statistically at par with SR_{100}+N_{368}, SR_{60}+N_{368} and SR_{80}+N_{276} kg ha^{-1} while the shortest plant height (112.1 cm) was found at SR_{60}+N_{184}, SR_{100}+N_{184} kg ha^{-1} and SR_{80}+N_{184} kg ha^{-1} combination. In conformity with this finding Harfe (2017) elucidated that the nitrogen fertilizer rate increased from the low (0) to high level (69 kg ha^{-1}) increased plant height of bread wheat.

Effective Tiller

Effective tiller number per row meter length was highly significantly ($p<0.01$) influenced by N rates and interaction effects of SR & N rates and significantly ($P<0.05$) influenced by main effects of SR (Table 6). Highest number of tillers was chronicled at the highest SR_{100} kg ha^{-1} followed by SR_{80} kg ha^{-1} while the lowest number of tillers was found at SR_{60} kg ha^{-1}. Increasing SR increased the total number of tillers per meter row length. This result is in agreement with Reddy *et al*. (2009) who indicated that the tiller number increased with the increase of seed rate and N fertilizer. N rates also significantly (P<0.05) affected the total number of tillers per row meter length. The highest number of tillers per row meter length was chronicled N_{368} kg ha^{-1} while a lower number of tillers were found N_{184} kg ha^{-1}. Nitrogen promotes activities essential for carbohydrate utilization and functions in plant promotion for rapid growth by increasing the number of total tillers (Saeed *et al*., 2012). The highest number of tillers of the shaga rice variety was found by the combined application of N_{276} along with D_{100} kg ha^{-1} but statistically equivalent with combined application of SR_{100}+N_{368}, SR_{80}+N_{368}, SR_{80}+N_{276}, SR_{60}+N_{368} kg ha^{-1}. These might be due to the attributed synergic effect in enhancing productive tillers production by the plant. The decrease in productive tillers might be associated with the greater number of stems produced as nitrogen fertilization increased, which may cause a smaller number of vegetative buds to become reproductive. Botella *et al*., 1993 found that the simulation of tillers with optimal application of N fertilizer was attributed to cytokine synthesis which is an essential hormone for cell division and shoot growth. Because high nitrogen rates induce the formation of large number of stems and leaves creating unfavorable conditions for yielding shade and lodging. The lowest number of tillers per row meter length (97.7) was found at the combination of SR_{60}+N_{184} kg ha^{-1} followed by the combined effects of SR_{60}+N_{184} kg ha^{-1} (98.8). Even though the plant height and culm length were significantly influenced by the combined effects of N fertilizer and seeding rate panicle length was highly significantly (P<0.01) affected by only the main effects of N rate. The tallest panicle length (20.3cm) was found with the application of N_{368} kg ha^{-1} and statistically at par with N_{276} kg ha-^{1} application. High tissue N concentration might have the toxic effect on plant growth resulting in stunted and reduced panicle length because of excessive application of N fertilizer (Smith & Hamel, 1999). However, the shortest panicle length per plant (18.6cm) was recorded with the supply of N_{184} kg ha^{-1}.

Effective Panicle and Panicle Length

Effective panicles were highly significant (P<0.01) by the main effects of SR and N rate. The combination of SR and N rates was also significantly (P<0.05) affected effective panicles (Table 6). The highest number of effective panicles (130.1) was recorded at SR_{100} kg ha^{-1} while the lowest number of effective panicles (105.8) was found SR_{60} kg ha^{-1}. This result is in line with Ahmed *et al*., 2014 that panicle number increased with increasing seeding rate.

The increase in seeding rate caused an increased number of panicles and a decreased number of grains per panicle and panicle weight (Reddy *et al.*, 2009). Among N rates, the highest number of effective panicles (128.6) was exhibited from the highest rate of N_{368} kg ha^{-1} and the lowest number of effective panicles (109.3) was produced with the application of N_{184} kg ha^{-1}. Number of effective panicles were significantly ($P<0.05$) affected by SR and N rates combinations. The highest number of effective panicles (135.8) was exhibited from $SR_{100}+N_{276}$ kg ha^{-1} combination while the lowest numbers of effective panicles (97.2) were chronicled $SR_{60}+N_{276}$ kg ha^{-1} combination. Hao Jiang *et al.*, 2021 found increasing density and N rate increase effective panicle number and number of plants.

Filled Spikelets and Number of Spikelets

Filled spikelets per panicle were significantly ($P<0.05$) affected by the main effects of SR and N rate but not by a combination of the two factors. The total spikelet number was influenced by the panicle efficiency and spikelet number per panicle and effective panicle number are intended to be the main factors determining yield due to the influence of improving panicle number per unit area similar to increasing yield of rice (Lee *et al.*, 2010). However, ample nutrient supply and optimal N fertilizer application strategies are essential for enhancing grain yield by overall increase of total number of spikelets. The highest number of filled spikelets was shown at the lowest SR_{60} kg ha^{-1} while the lowest number of filled spikelets (105.8) was chronicled at the highest SR_{80} kg ha^{-1} and statistically at par with SR_{100} kg ha^{-1} (105.7) (Table 6). Among N rates maximum number of filled spikelets (116.9) was recorded from N_{276} kg ha^{-1} application but statistically equivalent to N_{184} kg ha^{-1} application rate (116.4). However, the minimum filled spikelet number (101.2) was found from the maximum N_{368} kg ha^{-1}application rate. The nitrogen rate had a significant influence on the total number of spikelets per meter square by significantly influencing the number of panicles per meter square (Li *et al.*, 2022).

Culm Length

Culm length was significantly ($P<0.01$) affected by the main effects of N rates and interactions of SR & N rates but not by the main effects of SR. Among N rates, the longest culm length was found with the application of N_{368} kg ha^{-1} while the shortest culm length was found at N_{184} kg ha^{-1}. Regarding interaction effects longest culm length was attained at $SR_{80}+N_{368}$ kg ha^{-1} but statistically at par with $SR_{100}+N_{368}$, $SR_{80}+N_{276}$, $SR_{60}+N_{368}$ and $SR_{100}+N_{276}$ kg ha^{-1} combination while the shortest culm length was found $SR_{60}+N_{184}$, $SR_{100}+N_{184}$ and $SR_{80}+N_{184}$ kg ha^{-1} combination (Fig. 9). The combined effects of $SR_{60}+N_{368}$, $SR_{80}+N_{368}$ and $SR_{100}+N_{368}$ kg ha^{-1}

were highly significantly influenced culm length. The maximum rate of nitrogen absorption and culm length exhibited a close relationship. Light utilization efficiency might be improved and lodging minimized under high levels of nitrogen because it is important to minimize culm length, internode length and specific leaf weight (Wada *et al*., 1986).

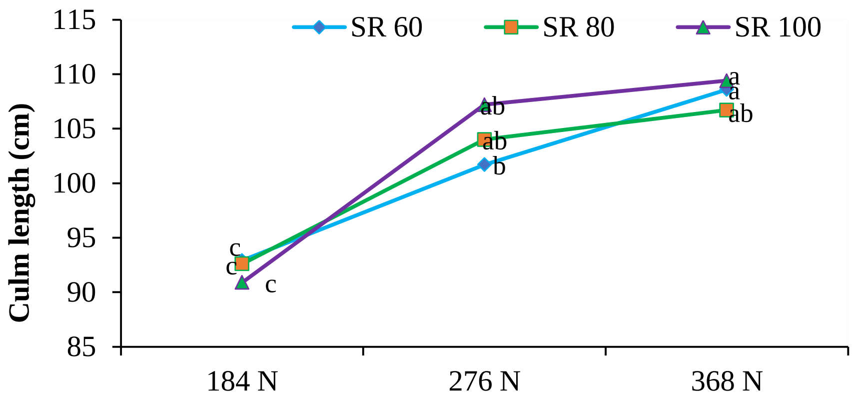

Figure 9. Influence of seed rate and N application rate interaction on the culm length of Shaga rice in North Achefer study site 2021-2022 cropping season

Table 6: Interaction effects of SR and N fertilizer rate on the growth yield and yield attributes of Shaga rice in North Achefer study site in 2020-2021 and 2021-2022 cropping season.

SR(kg ha^{-1})		PH (cm)	ET (No)	PL (cm)	FS (No)	FP (No)	DB (t ha^{1})	TSW (g)	SY (t ha^{-1})	HI (%)
60		117.0	106.4c	19.7	123.0a	105.8c	13.6	25.9	8.2	27.4
80		119.9	122.9b	19.9	105.8b	121.4b	14.3	25.6	9.7	25.1
100		118.5	131.0a	19.4	105.7b	130.1a	14.8	25.8	10.2	24.2
N (kg ha^{-1})										
184		112.5b	110.6b	18.6b	116.4a	109.3c	12.5b	26.3	7.4b	30.5a
276		119.7a	119.9ab	19.9a	116.9a	119.5b	15.0a	25.8	9.8a	25.5b
368		123.1a	129.8a	20.3a	101.2b	128.6a	15.2a	25.2	11.0a	20.7c
SR*N(kg ha^{-1})										
60	**184**	112.1c	97.7d	18.3c	125.9	98.2c	13.0	26.4	7.9bcd	29.3
	276	116.8bc	98.8cd	20.4ab	130.7	97.2c	13.8	26.0	7.7cd	29.5
	368	122.3ab	122.8abc	20.3ab	112.5	122.2abc	13.9	25.2	9.3abcd	23.5
80	**184**	113.3c	110.5bcd	19.0bc	112.5	108.9bc	11.9	25.9	6.8d	32.1
	276	122.1ab	125.8ab	20.0ab	114.1	125.5ab	15.5	26.3	10.3abcd	24.4
	368	124.1a	132.3ab	20.5a	90.7	130.0ab	15.6	24.6	11.9a	18.7
100	**184**	112.1c	122.5abcd	18.6c	110.7	120.8abc	12.8	26.5	7.7cd	30.0
	276	120.3ab	136.2a	19.4abc	106.0	135.8a	15.8	25.1	11.3abc	22.5
	368	123.0ab	134.3ab	20.2ab	100.4	133.5ab	15.9	26.5	11.8ab	20.1
CV (%)		4.9	17.6	6.0	18.8	17.9	13.4	8.2	3.6	11.4

Note: SR= Seed rate, N= Nitrogen rate, PH=Plant height, ET=Total tiller per row meter length, CL=Culm length, PL=Panicle length, FG=Filled spikelet number per panicle, FP=Fertile panicle per row meter length, DB= Dry biomass, GY=Grain Yield, TGW= Thousand grain weight, SY=Straw yield, HI=Harvest index

Physiological Traits

Leaf Area Indices

The leaf area index was significantly ($P<0.01$) influenced by the main effects of N rates and the combination of SR and N rates and significantly ($P<0.05$) influenced by the main effects of SR. The maximum leaf area index (3.6) was recorded at SR_{80} kg ha^{-1} and statistically alike with SR_{60} kg ha^{-1} while the minimum leaf area index (3.0) was found from SR_{100} kg ha^{-1}. Among N rates highest leaf area index (4.0) was exhibited at N_{276} kg ha^{-1} while the minimum leaf area index (3.0) was attained with application of N_{184} kg ha^{-1}. This result is in confirmed with the application of a high rate of N fertilizer to improve the above dry biomass and leaf area index (Kubar *et al*., 2022). However, increasing the application of N rates over N_{276} kg ha^{-1} decreased the leaf area index. Interaction effects at $SR_{100}+N_{184}$ and $SR_{100}+N_{368}$ kg ha^{-1} were found non-significant ($P<0.05$). The leaf area index was increased with decreasing SR and increasing N rates (Fig. 10). Increasing nitrogen rate and seeding rate increased leaf area indices at the flowering stage of rice growth, hence the grain yield increased with increased leaf area indices (Fagade and Datta, 1971). Conversely, the maximum leaf area index was recorded with interaction of $SR_{100}+N_{276}$ kg ha^{-1} (4.3), $SR_{60}+N_{368}$ kg ha^{-1} (4.2), $SR_{80}+N_{276}$ kg ha^{-1} (4.3) effects whereas the minimum leaf area index (2.2) was found with the combination of $SR_{100}+N_{368}$ kg ha^{-1}. However, the leaf area index was increased with the combination of $SR_{60}+N_{368}$ kg ha^{-1} but as SR and N levels increased leaf area index decreased. Similarly, the highest leaf area indices were obtained at the combination of $SR_{80}+N_{276}$ kg ha^{-1}. This result is in line with Jiang *et al*., 2021 who reported that seeding rate and N rate exerted a significant influence on the interception of photosynthesis active radiation and leaf area indices.

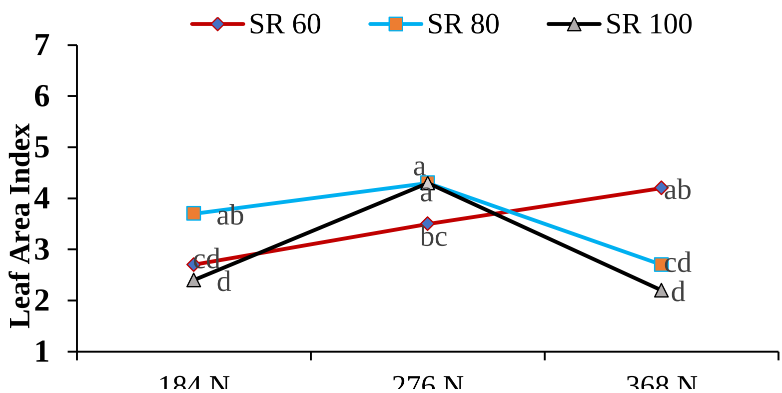

Figure 10. Influence of seed rate and N application rate interaction on the leaf area indices of Shaga rice in North Achefer study site 2021-2022 cropping season

Partial Factor Productivity of Nitrogen (PFPn)

Partial factor productivity of N was increased as the rate of N fertilizer application decrease without affecting the grain yield. This result conforms to research by Shi *et al.*, 2012, reported that excessive application of N fertilizer resulted in reduced NUE and soil pollution. Thus, improving NUE improves the rational utilization of agricultural resources. On contrary, reducing N fertilizer application, until the optimum, increased grain N uptake, NUE and grain yield.

Table 7: Partial factor productivity of nitrogen

N kg ha^{-1}	Grain Yield kg ha^{-1}	PFPn (kg kg^{-1})
184	5100.0	27.7
276	5300.0	19.2
368	4200.0	11.4

Application of high nitrogen fertilizer rate (N_{368} kg ha^{-1}) significantly reduced the partial factor productivity of N (Table 7). Research findings by Du *et al* 2021 are in line with our findings in which the plant density was higher by 30% and combined with a 15% lower nitrogen rate, increased N partial factor productivity by 24.7% and maize grain yield by 6.6% compared with low planting density combined with high N rate. Panayotova and Kostadinova, 2016 also found that partial N productivity of protein and grain of rice reduced by increasing the supply of N fertilizer in to the soil. The low N use of shaga rice variety indicates that the uptake was inefficient or higher than its requirement.

Harvest Index and Straw Yield

The straw yield was significantly affected by the main effects of N and interaction effects of SR & N rates but the main effects of SR were not significantly influenced straw yield. The highest straw yield (11.0 t ha^{-1}) was achieved with N_{368} kg ha^{-1} application while the lowest straw yield (7.4 t ha^{-1}) was observed with the supply N_{184} kg ha^{-1}. The highest straw yield (11.9 t ha^{-1}) was exhibited $SR_{80}+N_{368}$ kg ha^{-1} but statistically equivalent with combined application of $SR_{100}+N_{368}$, $SR_{100}+N_{276}$, $SR_{80}+N_{276}$ kg ha^{-1} (Table 6). Low straw yield (6.8 t ha^{-1}) was found $SR_{80}+N_{184}$ kgha^{-1} interaction effects and statistically at par with $SR_{60}+N_{267}$, $SR_{60}+N_{184}$, $SR_{100}+N_{184}$ kg ha^{-1} combination. However, the rice harvest indices were highly significantly (P<0.01) affected solely by N rates but not by SR and interaction effects of N rates & SR. High HI (30.5%) was observed N_{184}

kg ha^{-1} application while low HI (20.0%) was found in the highest N_{368} kg ha^{-1} application. This result is conforming to Pin Zhang *et al*., 2021, the application of N_{180} kg ha^{-1} increased the rice harvest index and N harvest index without significantly reducing grain yield or grain accumulation compared with the application of N_{240} and N_{300} kg ha^{-1}.

Grain Yield

The analysis of variance revealed that grain yield was significantly ($P<0.05$) influenced by the main effects of N rate, SR and their interactions (Fig. 11). The highest grain yield was achieved at SR_{60} kg ha^{-1} while the lowest grain yield was observed from SR_{100} kg ha^{-1} and statistically alike to SR_{80} kg ha^{-1}. This result is confirmed by Tahir Hussain Awan *et al*., 2022, elucidated that SR_{50} kg ha^{-1} was better when the sunlight was not a limiting factor. SR_{60} kg ha^{-1} was improved grain yield (5.3 t ha^{-1}) and then decreased at the SR_{80} and SR_{100} kg ha^{-1} 4.7 & 4.6 t ha^{-1} respectively (Fig. 11a). The lower seeding density, taller plant, greater tillering efficiency, lower sterility, and higher grain yield (Thapa *et al*., 2019). Grain yield was significantly ($P<0.05$) affected by N rates. The highest grain yield was found with the application N_{276} kg ha^{-1} while the lowest grain yield was attained N_{368} kg ha^{-1} as shown in (Fig. 11b). Better grain yield and straw at higher rates N fertilizer might be contributing in optimum rates of nutrients for crop uptake and translocation to sink and thereby expressing superior crop growth and development (Riste *et al*., 2017). Regarding combined effects, the highest grain yield (6.2 t ha^{-1}) exhibited at SR_{60}+N_{276} kg ha^{-1} combination while the lowest grain yield (3.7 t ha^{-1}) was found from SR_{80}+N_{368} kg ha^{-1} rates combination. Sharif Ahmed, 2016 confirmed N rate and seeding rate interaction show a significant effect on the grain yield of rice. Split application of N fertilizer with increasing rate increased grain yield by promoting panicles per meter square and bio-mass for poor soil fertility (Deng *et al*., 2015). However, grain yield was statically at par SR_{60}+N_{184}, SR_{60}+N_{276}, SR_{80}+N_{184}, SR_{80}+N_{276} and SR_{100}+N_{184} kgha^{-1} combination (Fig.11c). When N application rate exceeds the optimum yield reduced this might be due to excessive tillers and prolonged maturity. Yield is the most important and complex agronomic trait (Wang *et al*., 2012; Zeng *et al*., 2017; Zhang *et al*., 2017; Tang *et al*.,2020). High seeding rates and nitrogen fertilization suppressed yield due to a negative effect on the number of seeds per spike and the weight of individual grains. Furthermore, our results showed that for increased grain yield, optimum fertilization of N_{276} and optimum SR_{60} kg ha^{-1} were suitable for Shaga rice variety production at North Achefer area.

Economic Analysis

The highest net benefit 137,811Birr ha^{-1} with acceptable MRR 658.8% was attained at the combination of N_{276}+SR_{60} kg ha^{-1}. While the lowest net benefit 88,071 Birr ha^{-1} was produced with the supply of N_{368} kg ha^{-1} fertilizer along with SR_{80} kg ha^{-1} Shaga rice variety (Table 8).

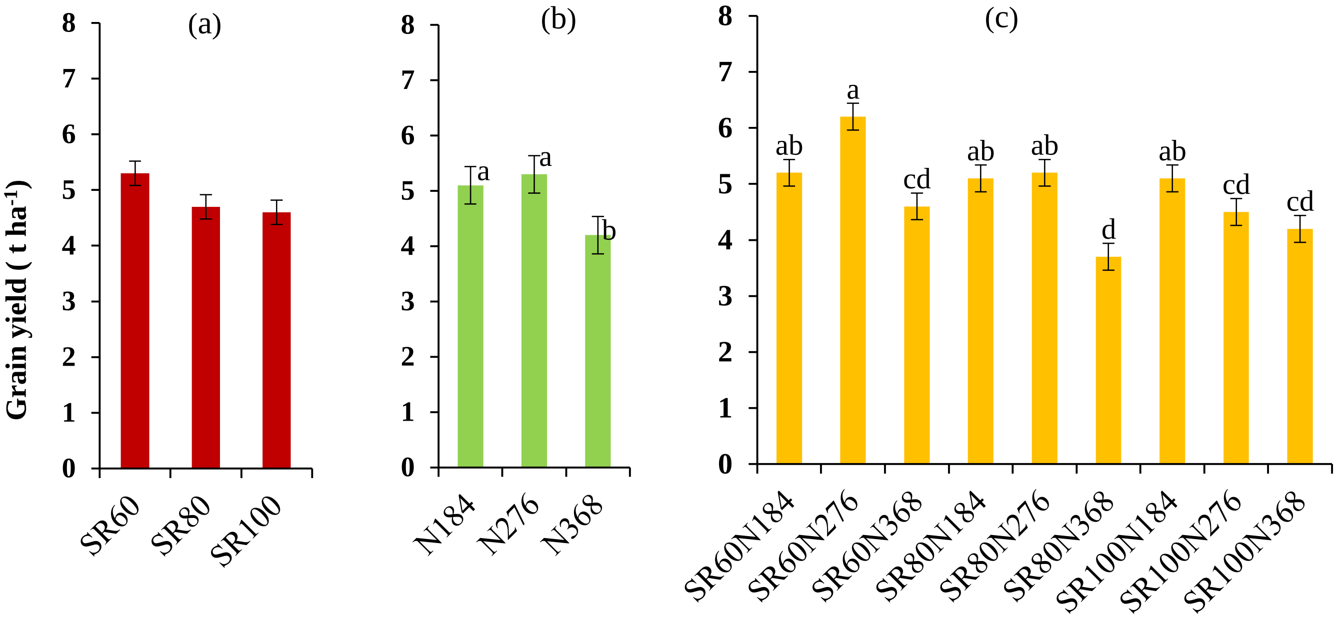

Figure 11Influence of seed rate (a), N fertilizer (b) and interaction effects (c) on the grain yield of Shaga rice in North Achefer experimental site 2021-2022 cropping season

Table 8. Grain and straw yield adjustment, total variable cost, gross and net benefit analysis of the study in North Achefer

SR (kg/ha)	N (kg/ha)	TVC (Birr/ha)	GY (t/ha)	SY (t/ha)	AGY (t/ha)	ASY (t/ha)	GB (Birr/ha)	NB (Birr/ha)	Dominance Analysis	MRR %
60	184	7280	5.2	7.9	5.3	7.1	126654	119374		
80	184	7840	5.1	6.8	5.7	6.12	122498	114658	D	
100	184	8400	5.1	7.7	6	6.9	124131	115731	D	
60	276	10080	6.2	7.7	4.8	6.9	147891	137811		658.4643
80	276	10640	5.2	10.3	4.9	9.3	131008	120368	D	
100	276	11200	4.5	11.3	4.6	10.2	117703	106503	D	
60	368	12880	4.6	9.3	3.3	8.4	116234	103354	D	
80	368	13440	3.7	11.9	3.1	10.7	101511	88071	D	
100	368	14000	4.2	11.8	2	10.6	112130	98130	D	

Where SR= Seed rate, N= Nitrogen fertilizer rate, TVC=total variable cost, GY=grain yield, SY=straw yield, AGY=Adjusted grain yield, ASY= Adjusted straw yield, GB=gross benefit, NB= net benefit, MRR= Marginal rate of return

Conclusions and Recommendation

The high inputs of nitrogen fertilizer and seeding rate bear a solemn environmental crisis and lower resource use efficiency. High rice grain yield was achieved at the expense of large inputs, seed rate and optimum chemically synthesized N fertilizer. Excessive N application rate reduces crop yield, PFPn and increases environmental pollution. Yield contributing factors leaf area index, effective panicles, filled spikelets per panicle and harvest index yield of Shaga rice regulated by optimization of N fertilizer application and seed rate. N application and seed rate significantly influenced the grain yield of Shaga rice. Maximum grain yield and yield components were achieved by avoiding excessive use of N and optimizing the compensation effect of increasing seed rate for decreasing N application. The application of N_{184} and SR_{100} kg ha^{-1} was the optimal combination to acquire higher grain yield, high nitrogen uses efficiency and net benefit of 151,456 Birr ha^{-1} and is recommended for Fogera study area. Finally, the combination of N_{276} kg ha^{-1} along with SR_{60} $kgha^{-1}$ gave better grain yield and high economic profitability of 137,811 Birr ha^{-1} and is recommended for North Achefer and for regions with similar agro-ecology conditions.

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