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Research article

Lowering nitrogen rates under the system of rice intensification enhanced rice productivity and nitrogen use efficiency in irrigated lowland rice

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ABSTRACT

Among the essential plant nutrients, nitrogen (N) is the most important and universally deficient in rice cropping systems worldwide. Despite different practices available for improvement of N management, nitrogen use efficiency (NUE) is still very low in rice, particularly under conventional management practices. This study was conducted to assess the effect of two crop management practices including the system of rice intensification (SRI) versus conventional management practices (CP) with four N application levels (60, 90, 120, and 150 kg N ha^{-1}) and absolute control (i.e., without N application) on rice growth, grain yield, and NUE. Experiments were established in split-plot randomized complete block design in three replicates. Crop management practices and N levels were treated as the main effect of main-plots and sub-plots, respectively with replicate blocks treated as random factors. Results indicated that deploying of SRI increased rice grain yield by 17.5 and 52.4% during wet and dry seasons, respectively compared with the CP. Rice grain yield was significantly ($p < 0.05$) higher in SRI than in CP at all levels of N application compared. The application of N at 120 and 60 kg ha^{-1} resulted in the increase in rice grain yields by 49 and 46.5%, respectively, relative to the absolute control during wet and dry seasons. Nitrogen application had a significant effect ($p < 0.05$) on agronomic nitrogen use efficiency (ANUE) and partial factor productivity (PFP). Results also indicated that agronomic nitrogen use efficiency (ANUE) was higher (27.2 kg grain kg^{-1} N) during the wet season with an application of 60 kg N ha^{-1}. Furthermore, higher ANUE (23.8 kg grain kg^{-1} N) was recorded during dry season with an application of 90 kg N ha^{-1}. The significant ($p < 0.05$) interaction effects of treatments were recorded on PFP between SRI and 60 kg N ha^{-1} during the wet (116.7 kg grain kg^{-1} N) and dry (105.8 kg grain kg^{-1} N) seasons. This study revealed that ANUE and PFP decreased with N application at the levels of 120 and 150 kg N ha^{-1} under SRI and CP during the two cropping seasons. The findings of the present study provide potential information that rice grain yield and higher NUE could be achieved at low N inputs under SRI, and thus reducing costs resulted from fertilizer inputs without compromising other environmental benefits.

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important grain crops, and more than three billion people consume rice as food worldwide (Zhao et al., 2021). Tanzania is the largest (947,303 km^2) country in East Africa and accounts for 9% (2.6 MT) of African rice production (30.8 MT) (Materu et al., 2018; FAOSTAT, 2014). In Tanzania, rice is the second most popular food crop after maize and the second most important commercial crop (Gowele et al., 2020). Although rice ranks as the second most consumed cereal in Tanzania, the productivity is estimated at 0.5 to 2 t ha^{-1} in the uplands and at 4.5 to 6.0 t ha^{-1} in the irrigated fields. These grain yields are far below the potential of 5 t ha^{-1} and 10–11 t ha^{-1} under proper resource endowment (Gowele et al., 2020; IRRI, 2013). Low rice productivity is associated with poor soil fertility, environmental degradation, intensive cropping systems, insufficient and imbalanced use of fertilizers, use of local varieties, and unawareness of farmers to the improved crop management practices (Baral et al., 2020; Thakur et al., 2013).

Among the essential plant nutrients, nitrogen (N) is universally deficient and the main yield limiting nutrient in rice cropping systems.

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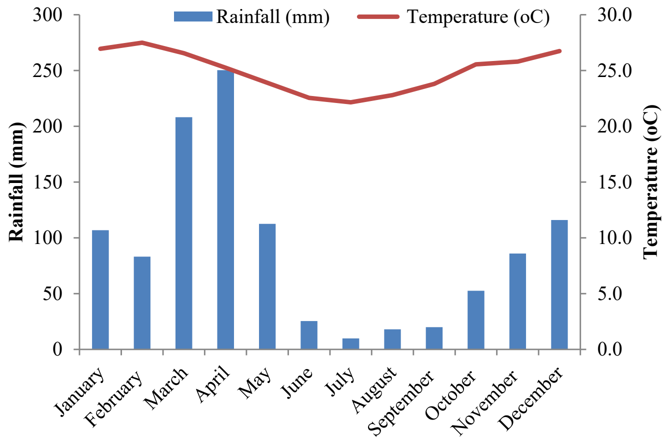

Figure 1. Average temperature and rainfall of Mkindo climatic conditions from 1999-2020. Source: Mtibwa weather station, Morogoro Tanzania.

Table 1. Details of experimental treatments.

Crop establishment method	Nitrogen levels kg N ha^{-1}	Age of seedling (d)	Spacing (cm)	Number of seedling hill^{-1}	Plant density (m^{-2})
SRI	ABC	10	25 × 25	1	256 (16)
	0N				
	60N				
	90N				
	120N				
	150N				
Conventional	ABC	25	20 × 20	3	400 (25)
	0N				
	60N				
	90N				
	120N				
	150N				

Key: SRI = System of rice intensification; ABC = absolute control. Values in parenthesis under the column of plant density are numbers of hill per unit area (m^{-2}) in respective plots.

Table 2. Average values of the selected soil chemical characteristics of composite topsoil sample (0–20 cm) from the experimental field in 2019.

Soil property	Mean Value	Unit
Soil pH (1:2.5)	5.36	
EC	0.03	dS m^{-1}
Cu	3.47	mg kg^{-1}
Zn	2.6	mg kg^{-1}
Mn	7.13	mg kg^{-1}
Fe	1.65	mg kg^{-1}
TN	0.11	%
OC	0.59	%
OM	1.02	%
Av P	7.71	mg kg^{-1}
SO_4^{2+}-S	1.04	mg kg^{-1}
Ca^{2+}	6.37	cmol$_c$ kg^{-1}
Mg^{2+}	1.51	cmol$_c$ kg^{-1}
Na^+	0.06	cmol$_c$ kg^{-1}
K^+	0.07	cmol$_c$ kg^{-1}
CEC	11	cmol$_c$ kg^{-1}

Key: OC = organic carbon; TN = total nitrogen; TP = total phosphorus; Av. P = available phosphorus; CEC = cation exchange capacity; EC = electric conductivity.

Table 3. Average values of the selected soil physical characteristics of composite topsoil sample (0–20 cm) from the experimental field in 2019.

Soil property	Value	Unit
Bulk density	1.59	g/cm3
Sand	69.8	%
Silt	7.6	%
Clay	22.6	%
Soil Texture class	Sand clay loam	
Field capacity	22.2	% volume
Wilting point	14.4	% volume
Available water	0.08	cm/cm
Saturation	40	% volume
Hydraulic conductivity	1.43E-06	mm/hr
Saturated hydraulic conductivity (Ks)	13.3	mm/hr
Matric potential	175	kPa.

The application of chemical N fertilizer is considered one of the options of improving grain yields in rice (Thakur et al., 2013; Jiang et al., 2004). The recovery of applied N and the proportion taken up by crop plants are usually less than 50% in traditionally-flooded paddy rice. These are attributed to rapid N losses through various pathways including nitrification-denitrification, ammonia volatilization, leaching, surface runoff, and drainage (Hameed et al., 2019; Chen et al., 2017). The low recovery of N may also result from blanket application of fertilizers which do not consider agro-climatic management conditions (Dobermann et al., 2003). The variations in the indigenous soil N supply capacities, crop N uptake efficiency, and soil moisture conditions may also affect N recovery (Baral et al., 2020). The production of rice by subsistence farmers makes use of traditional conventional methods (Katambara et al., 2013). Conventional methods consume large amounts of water resources as the practices involve keeping the soil flooded throughout the growing season. This increases the losses of N through different pathways (Zhao et al., 2021; Gowele et al., 2020; Islam et al., 2018; Yang et al., 2017).

The depletion of soil fertility and N deficiency are the major challenges in rice cropping systems on smallholder farms of Tanzania (Massawe, 2016). A study conducted in nine farms of Mkindo Farmer Managed irrigation scheme in Tanzania showed that 100% of the soils were low in total N (Jumanne, 2016). Another study conducted by Amuri et al. (2013) depicted that some selected paddy growing soils in irrigation schemes of Tanzania were low in total N. Nitrogen use efficiency (NUE) is indicates the utilization of nitrogen in rice plants (Bagheri Novair et al., 2021). The NUE is an established metric used to benchmark N management (Congreves et al., 2021). It is also used for environmental and economic objectives of minimizing nutrient losses and the negative impact on surrounding water, air and ecosystems, as well as reducing costs associated with excessive fertilizer inputs (Congreves et al., 2021; Galloway et al., 2014). The NUE is defined as the fraction of applied N uptake by plant, rarely exceeding 30% in lowland rice (Baral et al., 2020).

The losses of N in rice agroecological cropping systems can be mitigated through the system of rice intensification (SRI). The system involves six principles, including water management under alternate wetting and drying (AWD) forms of water saving irrigation (Bagheri Novair et al., 2021). The practice maintains shallow water depth with intermittent drying rather than continuous flooding (Thakur et al., 2013). Therefore, there is a need to assess how a modified crop-soil-water management regime as proposed by SRI theory and practice will affect rice growth, grain yield, and NUE in local conditions. This study compared rice growth, grain yields and factor productivity for plants grown using SRI methods with those under conventional practices. The specific objectives were three-fold: (i) to assess the effects of different

Table 4. Effect of crop management practices and N levels on plant height (cm) during wet season.

Treatment	Maximum tillering	panicle initiation	Booting	Dough	At harvest
Crop management practices (CMP)					
SRI	32.0	57.0	77.2	97.8	96.3
CP	35.9	58.0	86.6	88.5	89.8
LSD (0.05)	NS	NS	1.18	5.33	NS
F Pr.	0.075	0.368	<.001	0.017	0.205
Nitrogen levels (N)					
ABC	31.4ab	53.3a	70.8a	82.2a	85.1a
0 N	30.7a	53.2a	72.3a	84.5a	90.2a
60 N	34.3bc	56.9bc	84.5b	93.9b	95.8b
90 N	36.5c	59.3bc	85.9b	96.7bc	95.2b
120 N	35.3c	58.5abc	87.2b	98.5bc	96.0b
150 N	35.4c	63.7c	90.8b	103.0c	96.2b
LSD (0.05)	2.92	NS	6.75	7.05	5
F Pr.	0.002	0.006	<.001	<.001	<.001
Interactions (CMP × N)					
LSD 0.05	NS	NS	NS	NS	NS
F Pr.	0.451	0.159	0.344	0.93	0.27

Key: LSD = least significant difference; F Pr. = F probability; NS = not significant. Mean values followed by different letters denote significant difference between treatments at $p < 0.05$.

Table 5. Effect of crop management practices and N levels on plant height during dry season.

Treatment	Panicle initiation	Dough	At harvest
Crop management practices (CMP)			
SRI	57.3	90	87.7
CP	55.2	78.1	77.4
LSD (0.05)	NS	4.919	3.933
F Pr.	0.247	0.009	0.036
SE	0.782	1.36	1.341
Nitrogen levels (N)			
ABC	50.7a	71.9a	79.8
0 N	50.6a	75.6a	80.7
60 N	56.7bc	84.2b	85.1
90 N	55.7b	89.2bc	81.3
120 N	60.6cd	89.8bc	83.9
150 N	63.1d	92.9c	84.7
LSD (0.05)	3.896	7.168	NS
F Pr.	<.001	<.001	0.455
SE	1.354	2.355	1.035
Interactions (CMP × N)			
SRI-ABC	46.5a	69.1a	77.2a
SRI-0	55.0b	76.1ab	88.3bc
SRI-60	59.9bc	90.4c	88.9c
SRI-90	55.5b	101.7d	89.9c
SRI1-20	63.3c	100.8d	89.7c
SRI1-50	63.9c	101.6d	92.1c
CP-ABC	54.9b	74.8ab	82.3abc
CP-0	46.2a	75.1ab	73.0a
CP-60	53.6b	79.2ab	81.3abc
CP-90	55.9b	76.6ab	72.6a
CP-120	58.0bc	78.8ab	78.1ab
CP-150	62.4c	84.2bc	77.4a
LSD (0.05)	5.819	9.506	9.741
F Pr.	0.003	0.001	0.028
SE	1.915	3.33	9.633

Key: LSD = least significant difference; F Pr. = F probability; NS = not significant. Mean values followed by different letters denote significant difference between treatments at $p < 0.05$.

N-fertilizer application levels on growth and grain yield and yield parameters; (ii) to assess interaction effects of crop management practices and N levels on NUE; and (iii) to assess whether N-fertilizer applications could be reduced through SRI methods without significant reduction in grain yield.

2. Materials and methods

2.1. Study site

Two consecutive field experiments using the same plots were conducted during the 2019 and 2020 cropping seasons. The experiment conducted during wet season covered the period of 19th February 2019 - 5th July 2019 and the dry season started on 5th September 2019 and ended on 21st January 2020. Field experiments were conducted at Mkindo Farmer Managed irrigation scheme located in Mkindo village in Mvomero District and Morogoro Region of Eastern. The district is located between latitudes 6°16′ and 6°18′ S and longitudes 37°32′ and 37°36′ E and its altitude ranges between 345 to 365 m above sea level. The experimental site is located at latitude 6°15′13″ S and longitude 37°32′19″ E. The climate is tropical with two distinct dry and wet seasons. The average monthly maximum temperature at the experimental site ranges between 35.1 °C and 28.5 °C in February and June while the average monthly minimum temperature ranges between 20.4 °C and 15.8 °C in January, March and July. The mean relative humidity is 67.5% and the area experiences bimodal rainfall regime with short rains extending from October to December (OND) and long rains from March to May (MAM). The long rains (*masika*) range between 112.6 and 250.3 mm with a total rainfall of 571.1 mm while the short rains (*vuli*) vary between 52.6 and 116 mm with a total rainfall of 254.5 mm. The average annual rainfall ranges between 716.5 and 1503.5 mm (Gowele et al., 2020; Reuben et al., 2016; Kahimba et al., 2013). The average temperature and rainfall of Mkindo site for the past 21 years (1999–2020) are shown in Figure 1.

2.2. Soil sampling and analysis

Soils were sampled before establishing experiments and analyzed, where ten spots were sampled at a soil depth of 0–20 cm. The quartering procedure was used to get a composite soil sample which was subject to routine laboratory analysis. The soil samples were air-dried, ground and sieved to pass through 2 mm mesh and analyzed for the particle size distribution for textural class by Bouyoucos hydrometer method (Day, 1965), soil pH electrochemically in 1:2.5 (weight/volume) soil: water suspensions (MacLean, 1982). Organic carbon was measured by the wet digestion (oxidation) method of Walkely-Black (Nelson and Sommers, 1982) with total nitrogen measured by micro-Kjedahl digestion distillation method (Bremner and Mulvaney, 1982). Soil available phosphorus by Bray and Kurtz (1945), and exchangeable bases (Ca, Mg, K, and Na) were determined by saturating the soil samples with 1 M NH_4OAc solution at pH 7.0. Exchangeable Ca and Mg were determined by using atomic absorption spectrophotometry (AAS), while exchangeable Na and K were measured by flame photometer from the same extract (Chapman, 1965). Extractable micronutrients (Zn, Cu, Mn, and Fe) were extracted by diethylene triamine pentaacetic acid (DTPA) method and were measured by AAS (Lindsay and Norvell, 1982).

2.3. Experimental design and treatment details

The experiment was arranged in a split-plot randomized complete block design in three replicates with two factors (crop management practices in main plots and nitrogen levels in sub-plots) in each cropping season. The main plot was then divided into six subplots of 4 m × 4 m (16 m^2) in size. All

Table 6. Effect of crop management practices and N levels on the number of tillers during wet season.

Treatment	Mid tillering	Panicle initiation	Booting	Dough	At harvest
Crop management practices (CMP)					
SRI	4.3	9.6	13.0	15.0	14.5
CP	7.1	9.6	9.6	9.9	9.1
LSD 0.05	0.48	NS	1.586	NS	2.413
F Pr.	0.002	0.451	0.012	0.065	0.011
Nitrogen levels (N)					
ABC	4.7a	8.0a	8.5a	9.0a	8.7a
0 N	4.5a	8.8a	8.9a	9.8a	8.8a
60 N	6.0b	8.5a	11.6b	12.9b	12.7b
90 N	6.1b	9.7ab	12.2b	12.8b	13.2b
120 N	6.3b	10.7bc	13.3b	15.2b	13.6b
150 N	6.5b	11.9c	13.4b	14.8b	13.8b
LSD 0.05	1.27	1.621	2.193	2.268	1.72
F Pr.	0.013	<.001	<.001	<.001	<.001
Interactions (CMP × N)					
LSD 0.05	NS	NS	NS	NS	2.524
F Pr.	0.117	0.195	0.971	0.931	0.004

Key: LSD = least significant difference; F Pr. = F probability; NS = not significant. Mean values followed by different letters denote significant difference between treatments at $p < 0.05$.

Table 7. Number of tillers during dry season as affected by crop management practices and N levels.

Treatment	Panicle initiation	Milk	Harvest
Crop management practices (CMP)			
SRI	9.2	15.9	14.1
CP	11.5	10.4	10.4
LSD (0.05)	0.798	3.019	3.172
F Pr.	<.001	0.016	0.037
SE	0.272	0.541	0.572
Nitrogen levels (N)			
ABC	8.6a	8.6a	8.7a
0 N	8.6a	10.3a	9.9ab
60 N	11.1bc	13.4b	12.5bc
90 N	10.3b	15.4b	14.1c
120 N	11.5bc	15.5b	14.4c
150 N	12.0c	16.0b	13.8c
LSD (0.05)	1.243	2.785	2.947
F Pr.	<.001	<.001	0.002
SE	0.471	0.937	0.991
Interactions (CMP × N)			
SRIABC	7.0	8.9	8.3a
SRI0N	8.5	12.5	12.9bcd
SRI60N	9.6	16.6	16.7de
SRI 90N	9.13	20.3	17.6e
SRI120N	10.7	18.7	14.5cde
SRI150N	10.5	18.6	14.7cde
CPABC	10.3	8.3	9.1ab
CP0 N	8.7	8.0	6.9a
CP60 N	12.5	10.1	8.3a
CP 90 N	11.5	11.7	10.7abc
CP120 N	12.3	12.3	14.3cde
CP150 N	13.6	12.3	13.0bcde
LSD (0.05)	NS	NS	4.087
F Pr.	0.114	0.119	0.015
SE	0.666	1.324	1.401

Key: LSD = least significant difference; F Pr. = F probability; NS = not significant. Mean values followed by different letters denote significant difference between treatments at $p < 0.05$.

plots were surrounded by consolidated bunds, and 2 m buffer strips were left between the main plots and 1 m for subplots. This was to provide access pathways and more importantly to minimize lateral movement of irrigation water and fertilizers between the plots. The detail of treatments adopted is given in Table 1. Fertilizer treatments comprised six nitrogen levels including absolute control (ABC) which did not receive any N but received P and K fertilizers.

The level of 120 kg N ha^{-1} represents the existing blanket recommendation for rice growing in the study area. Nutrient N was applied from urea (CON$_2$H$_4$, 46% N) fertilizer in two splits that is 50% of the dose at fourteen days after transplanting and another 50% of the dose at panicle initiation stage. Phosphorus was applied at a full dose of 60 kg P ha^{-1} from triple superphosphate (45% P$_2$O$_5$) and potassium at a full rate of 60 kg K ha^{-1} from muriate of potash (60% K$_2$O). Phosphorus and potassium fertilizers were applied by broadcasting and mixed with soil during transplanting.

2.4. Crop establishment

A rice variety TXD 360 semi-aromatic, referred to commonly as SARO 5 was used as a test variety. This is mid-late season rice variety (120–130 days cycle), which is grown under rainfed or irrigated ecologies with a yield potential of 7.0–8.5 t ha^{-1}. It is medium in stature, resistant to lodging, and has good tillering ability (more than 20 tillers per hill depending on management). Seedling nurseries for each season were prepared by pudding the soil. Before sowing in the nursery, seeds were prepared by separating the unfilled grains from filled grains through priming with clean water to get vigorous plant. In SRI plot, a square grid pattern was created on the soil surface using a wooden marker at distances of 25 cm × 25 cm between perpendicular lines. Ten days after seedlings establishment, one seedling was transplanted per hill. Rotary (cono-weeder) and hand were used in removing the weeds. In CP, 25-day-old seedlings were transplanted in puddled field at a spacing of 20 cm × 20 cm while keeping three seedlings per hill.

2.5. Irrigation water management

Continuous flooding irrigation was done in CP plots following farmers' practices. For the first 14 days after transplanting, a 3–5 cm water depth was maintained under CP and SRI irrigation regimes to facilitate seedling recovery. Thereafter, plots under CP were continuously flooded with 3–10 cm water level until 10 days before harvest. After the first 14 days of transplanting the SRI plots were kept with a layer of 2 cm of water until 14 days after panicle initiation stage. Furthermore, the plots were maintained without standing water for 3–5 days before re-irrigation under the same SRI plots. Thereafter, the SRI plots were re-irrigated to 2 cm when water depth dropped to 15 cm below the soil; this took 2–3 days interval. The soil water depths were measured and monitored in each SRI plot using PVC pipe installed in the plots at 15 cm depths (Lampayan et al., 2015).

PVC pipes installed in SRI plots, with perforated holes with a diameter of about 0.5 cm each and spaced about 2 cm away from one another. The tube was buried vertically 15 cm into the soil and half of its length protrudes above the soil surface. Pipes were installed near to the bund for easy water monitoring. After burying the soil inside the tubes was removed so as bottom level is visible. Water level inside the tube was checked and was the same the outside. Each of the main plots was irrigated separately. Irrigation water was provided from an irrigation canal and measured by a plastic ruler inserted into the plots. The water depth was measured daily at 8:00 am and 14:00 pm GMT using a 101 p7 flat tape water level meter (Solinst Canada Ltd, Geogetown, Ontario Canada).

Table 8. Effects of crop management practices and N levels on leaf chlorophyll content.

Treatment	Panicle initiation	Milk
Crop management practices (CMP)		
SRI	43.8	46.9
CP	40.2	46.3
LSD (0.05)	1.832	NS
F Pr.	<.001	0.377
SE	0.625	0.437
Nitrogen levels (N)		
ABC	40.2ab	43.5a
0	39.5a	45.1ab
60	41.3ab	46.9bc
90	43.5bc	47.7c
120	44.7c	47.2bc
150	43.5bc	49.0c
LSD (0.05)	3.173	2.302
F Pr.	0.018	<.001
SE	1.082	0.757
Interactions (CMP × N)		
SRIABC	37.4a	43.2
SRI 0	40.4abcd	45.7
SRI60	44.7cdef	46.2
SRI90	45.2def	47.5
SRI120	48.9f	48.1
SRI150	46.1ef	50.4
CPABC	43.0bcde	43.7
CP0	38.6ab	44.5
CP60	37.9a	47.6
CP90	41.8abcde	48.0
CP120	40.5abcd	46.4
CP150	39.7abc	47.6
LSD (0.05)	5.014	NS
F Pr.	0.002	0.372
SE	4.487	1.071

Key: LSD = least significant difference; F Pr. = F probability; NS = not significant. Mean values followed by different letters denote significant difference between treatments at $p < 0.05$.

Table 9. Root characteristics as affected by crop establishment methods and nitrogen levels.

Treatment	Fresh weight hill $^{-1}$(g)	Length hill^{-1} (cm)	Volume hill^{-1} (ml)	Dry weight hill^{-1} (g)
Crop management practices (CMP)				
SRI	36.2	12.6	33.8	10.4
CF	29.2	11.1	27.5	6.7
LSD (0.05)	6.74	0.726	5.31	1.9
F Pr.	0.043	<.001	0.022	<.001
SE	2.3	0.248	1.81	0.648
Nitrogen levels (N)				
ABC	22.7	11.5	21.6	7.2a
0 N	34.7	12.3	31.7	6.1a
60 N	33.0	11.2	33.0	7.9a
90 N	35.5	12.4	31.2	9.5a
120 N	33.4	11.3	31.2	7.8a
150 N	36.9	12.4	35.2	13.0b
LSD (0.05)	NS	NS	NS	3.291
F Pr.	0.193	0.174	0.086	0.004
SE	3.98	0.429	3.14	1.122
Interaction (CMP x N)				
SRIABC	27.8	11.8	22.8	10.4
SRI0 N	47.2	13.2	37.3	7.3
SRI60 N	38.8	11.9	38.7	8.8
SRI 90 N	31.6	13.9	35.0	11.9
SRI120 N	32.2	11.4	32.3	9.0
SRI150 N	39.6	13.2	36.7	15.2
CPABC	17.7	11.1	20.3	4.0
CP0 N	22.2	11.3	26.0	4.8
CP60 N	27.2	10.5	27.3	7.1
CP 90 N	39.5	10.9	27.3	7.1
CP120 N	34.4	11.2	30.1	6.5
CP150 N	34.2	11.6	33.7	10.8
LSD (0.05)	NS	NS	NS	NS
F Pr.	0.102	0.285	0.785	0.679
SE	5.63	0.606	4.43	1.587

Mean values followed by different letters denote significant ($P < 0.05$) difference between treatments by DMRT; NS: not significant.

2.6. Assessment of growth contributing characters

Plant height: - five plants from each plot were selected randomly and measured at different stages of crop growth to maturity. Plant height was measured from the plant base to the tip of the tallest leaf but for the mature plants, the measurement was performed from the base to the tip of the tallest panicle. *Number of tillers per hill*: - were counted from five plants in each experimental plot on the same day that the plant height was measured. *Chlorophyll content (CC)*: - five hills were randomly selected and 5 flag leaves were selected for the measurements at panicle initiation and milk grain stage of the rice plant using LEAF CHL PLUS meter (FT Green LLC, 1000N.West St.Suite 1200# 638 Wilmington, DE19801 USA, www.atleaf.com).

Assessment of root growth: - the measurements of root length, root fresh and dry weightsm and volume were taken at panicle initiation stage from five hills of each subplot during wet season as described elsewhere (Xu et al., 2019; Pascual and Wang, 2017; Ndiiri et al., 2012).

2.7. Assessment of grain yield and yield components

The yield components measured were harvest index, straw yield, effective and non-effective tillers, number of panicle per square meter, panicle length, panicle weight, number of panicle per hill, grain number per panicle, grain weight per panicle, and filed and unfilled grains per panicle. Grain yield was determined in a net plot of 2 m × 2 m i.e., 64 and 100 hills in SRI and CP plots, respectively with exclusion of the border rows. The straw (including peduncle and rachis) was oven-dried (Memmert 854 oven, MEMMERT GmbH + Co. KG Schwabach, 91126 Bavaria, Germany) at 60 °C for 72 h to constant weight. Grains were sun dried before determining weight and moisture. Grain moisture was measured by 8988N grain moisture meter (Xiamen Hyhoo Imp. & Exp. Co., Ltd, Fujian, China) and adjusted to 14% moisture content. Grain and straw yields obtained were dried in the sun and weighed by Endel Precision weighing scale (EJB-NB-6000, Dubai) to record the yield/plot and finally converted to t ha^{-1}. The grain harvest index was calculated based on the ratio of grain yield to total biomass produced.

The number of productive and non-productive tillers was counted from tillers with panicles bearing at least one filled grain. The panicle weight was obtained at a constant weight after oven drying at 70 °C for 72 h. Panicle length was recorded from the basal node of the rachis to the apex of each panicle with a centimeter rule. The filled spikelets were separated from the unfilled spikelets using a HMC 67 seed blower (Hoffman Manufacturing Inc. Corvallis, OR 97330 USA) and the grain filling rate was calculated on mass basis as the ratio of filled grains weight to the total grain weight per panicle multiplied by 100. One thousand (1000) grains were randomly selected and counted from the harvested grains in each replicate for 1000-grain weight determination using seed counter Seedburo 801 Count-A-Pak®, 801-10/C model, serial Co 655 Chicago Illinois USA.

Table 10. Effects of crop management practices and N levels on straw yield, harvest index, grain yield and 1000 grains weight of rice.

Treatment	Straw yield (t ha^{-1})		Harvest index		Grain yield (t ha^{-1})		1000 grains weight (g)	
Season(s)	WS	DS	WS	DS	WS	DS	WS	DS
Crop management practices (CMP)								
SRI	5.1	3.9	0.6	0.6	6.7	6.4	32.8	29.8
CP	4.5	2.6	0.6	0.6	5.7	4.2	38.1	31.2
LSD (0.05)	NS	0.59	NS	NS	0.99	0.96	0.02	NS
F Pr.	0.062	<.001	0.79	0.474	<.001	<.001	<.001	0.174
SE	0.19	0.2	0.01	0.02	0.19	0.19	0.82	0.598
Nitrogen levels								
ABC	2.9a	2.2a	0.6b	0.7	4.1a	4.1a	33.9	28.8
0	3.0a	2.9ab	0.6b	0.6	4.9a	4.3a	33.9	30.5
60	4.9b	3.0ab	0.6b	0.7	6.6b	5.3b	35.7	30.9
90	5.6bc	3.8bc	0.6b	0.6	7.1b	6.3b	37.8	32.5
120	6.0c	4.1c	0.6b	0.6	7.3b	5.7b	37.7	30.9
150	6.6c	3.5bc	0.5a	0.6	7.2b	6.1b	33.8	29.5
LSD (0.05)	0.96	1.03	0.04	NS	0.57	0.55	NS	NS
F Pr.	<.001	0.01	0.001	0.992	0.003	<.001	0.156	0.252
SE	0.33	0.35	0.01	0.03	0.34	0.33	1.41	1.035
Interaction (CMP x N)								
SRIABC	3.2	2.8	0.6b	0.6	4.5	4.8	32.9	26.9
SRI0 N	3.6	3.5	0.6b	0.6	5.0	5.5	32.8	30.5
SRI60 N	5.2	3.5	0.6b	0.6	7.0	6.4	32.6	30.4
SRI 90 N	6.2	4.8	0.6b	0.6	8.1	7.7	32.9	33.0
SRI120 N	5.8	4.8	0.6b	0.6	7.4	6.6	32.7	31.2
SRI150 N	6.5	3.9	0.6b	0.7	8.1	7.3	32.8	26.9
CPABC	2.6	1.6	0.6b	0.7	3.7	3.3	34.9	30.8
CP0 N	2.4	2.3	0.7bc	0.6	4.8	3.0	34.9	30.4
CP60 N	4.6	2.5	0.6b	0.6	6.1	4.3	38.8	31.5
CP 90 N	4.9	2.8	0.6b	0.6	6.2	5.0	42.6	31.9
CP120 N	6.2	3.4	0.5a	0.6	7.2	4.7	42.6	30.6
CP150 N	6.6	3.1	0.5a	0.6	6.3	4.8	34.9	32.0
LSD (0.05)	NS	NS	0.06	NS	NS	NS	NS	NS
F Pr.	0.407	0.843	0.045	0.836	0.356	0.774	0.144	0.2
SE	0.47	0.5	0.02	0.04	0.48	0.46	2.00	1.464

WS: wet season; DS: dry season ^{1}NS = non-significant.
Mean values followed by different letters denote significant ($P < 0.05$) difference between treatments by DMRT.
NS: not significant.

2.8. Assessment of nitrogen use efficiency

Different measures of nitrogen use efficiency (NUE) such as agronomic nitrogen use rate, partial factor productivity nitrogen of applied N and nitrogen contribution rate (FCRN) were calculated by Eqs. (1), (2), and (3) as described by Thakur et al. (2013).

$$\mathrm{ANUE} = \frac{\mathrm{Y} - \mathrm{Y}_0}{\mathrm{F}} \tag{1}$$

$$\mathrm{PFP_N} = \frac{\mathrm{Y}}{\mathrm{F}} \tag{2}$$

$$\mathrm{FCR_N} = \frac{\mathrm{Y} - \mathrm{Y}_0}{\mathrm{Y}} \times 100 \tag{3}$$

Where ANUE for agronomic N use efficiency, PFPN for partial factor nitrogen productivity, FCRN for nitrogen contribution rate, Y for grain yield with nitrogen application, Y_0 for grain yield without nitrogen application, F for amount of nitrogen applied.

2.9. Statistical analyses

In assessing the effects of factors on the measured variables, the fixed main effects were the cropping systems and N application levels, whereas replicate blocks were treated as random effect. A TWO–WAY ANOVA was performed and the factor effects model is as shown in Eq. (4).

$$\mathrm{Y}_{ij} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ij} \tag{4}$$

Where *Yij* is the observed measured variable in the *ijth* factors; μ is the overall (grand) mean; α_i and β_j are the main effects of the factors cropping systems and N levels, respectively; $(\alpha\beta)_{ij}$ is the two-way (first order) interactions between the factors; *εij* is the random error associated with the observation of measured variables in the *ijth* factors.

The significant effects of cropping systems and N levels on the measured variables identified in Eq. (4) were isolated by a post-hoc Tukey's-HSD test at a threshold of 5% using GenStat Discovery Edition 15. All statistics followed procedures described by Gomez and Gomez (1983).

3. Results and discussion

3.1. Soil characteristics

The soil in the study area is moderately acid (pH 5.5–6.0) as shown in Table 2 (Landon, 1991). This pH range is generally suitable for rice production (Halim et al., 2018). Soil pH affects the availability and solubility of essential plant nutrients such as N, P, Ca, Mg, S, and K

Table 11. Effects of crop management practices and fertilizer N levels on panicle components of rice.

Parameter	Panicle weight (g)		panicle length (cm)		Number of panicle hill^{-1}		Number of panicle m^{-2}		Spikelet panicle^{-1}	
Season	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS
Crop management practices (CMP)										
SRI	4.5	3.9	22.8	23.1	14.5	14.1	232.2	226.0	146.1	153.6
CP	3.5	2.2	22.0	20.3	9.1	11.0	228.1	274.2	113.5	86.9
LSD (0.05)	0.55	1.17	NS	NS	1.005	NS	NS	NS	18.7	17.92
F Pr.	0.001	0.023	0.069	0.076	<.001	0.056	0.671	0.118	0.002	0.004
Nitrogen levels (N)										
ABC	3.3a	2.7a	20.7a	20.4	8.7a	8.7a	175.1a	180.8a	118.5	103.0a
0 N	3.6a	2.7a	21.3ab	20.8	8.8a	9.9a	174.3a	189.3a	119.7	100.0a
60 N	3.7a	3.3ab	22.3ab	22.7	12.7b	13.5b	246.3b	263.0b	123.0	138.1b
90 N	4.3ab	3.6b	22.7bc	22.8	13.2b	14.6b	250.2b	285.0b	136.4	143.3b
120 N	4.8b	2.8a	24.4c	21.1	13.6b	14.4b	264.8b	294.1b	146.3	107.5a
150 N	4.2ab	3.1ab	23.0bc	22.4	13.8b	14.2b	269.9b	288.2b	135.0	128.7ab
LSD (0.05)	0.96	0.66	1.67	NS	1.74	3.015	34.36	60.18	NS	26.63
F Pr.	0.044	0.041	0.003	0.052	<.001	0.001	<.001	0.001	0.434	0.008
Interaction (CMP x N)										
SRIABC	3.9	3.2	20.9	21.2	9.6abc	8.3	153.6	133.3	136.1	118.9
SRI0 N	4.1	3.5	22.2	22.4	10.3bc	12.9	165.3	206.9	138.3	126.1
SRI60 N	4.0	4.0	22.7	23.7	16.0d	14.7	256	267.7	142.0	168.2
SRI 90 N	5.0	5.1	23.5	24.9	17.7d	17.6	283.7	281.6	162.8	199.1
SRI120 N	5.5	3.6	25.1	22.4	16.5d	14.5	264.5	231.5	165.3	135.5
SRI150 N	4.3	4.1	22.8	24.1	16.9d	14.7	269.9	234.7	132.2	173.6
CPABC	2.7	2.1	20.6	19.6	7.3a	9.1	196.7	228.3	100.8	87.1
CP0 N	3.1	2.0	20.4	19.2	7.9ab	6.9	183.3	171.7	101.1	75.1
CP60 N	3.4	2.6	21.9	21.6	8.7abc	10.3	236.7	258.3	104.0	108.0
CP 90 N	3.5	2.2	21.8	20.7	9.5abc	11.5	216.7	288.3	109.9	87.5
CP120 N	4.1	1.9	23.7	19.7	10.6bc	12.3	265	356.7	127.2	79.6
CP150 N	4.0	2.1	23.3	20.7	10.8c	13.7	270	341.7	137.7	83.7
LSD (0.05)	NS	NS	NS	NS	2.461	4.202	NS	86.57	NS	NS
F Pr.	0.765	0.115	0.724	0.719	0.004	0.05	0.059	0.043	0.561	0.06

Mean values followed by different letters denote significant ($P < 0.05$) difference between treatments by DMRT.
NS: not significant.

(Mng'ong'o et al., 2021). The soil is sand clay loamy in texture, with water field capacity of 22.2% volume and wilting point of 14.4% volume (Table 3). The soil is low in total nitrogen (0.11%), which is one of the yield limiting nutrient in rice cropping systems. This finding necessitates the need for application of nitrogen fertilizer to improve rice yield. The soil is low in organic carbon, organic matter, and exchangeable potassium. Other nutrients including Ca, Cu, Fe, Zn, and Mn were in the acceptable ranges for crop growth and production (Landon, 1991).

3.2. *Rice growth contributing characters*

Plant height increased with the increase in nitrogen application (Tables 4 and 5). The significant effect of CMP in plant height was observed at booting and dough stages in wet season and at dough and harvest in dry season. The tallest plants were measured in SRI against the measurements taken in plants under CP. Nitrogen levels had a significant effect on plants in all stages of crop growth in dry and wet seasons but without significant effect on growth at panicle initiation. The interactions between treatments were significant on the measured growth variables in dry season. Shorter plants were recorded in absolute control plots and in plots where N was not applied during the two cropping seasons.

The highest plant height recorded in SRI could have been contributed by the reduced shock at the initial stage of growth through planting of young seedlings with less leaf area. This is likely to cause stimulation increase in cell division and hence facilitate elongation, which increases plant height (Vijayakumar et al., 2006). Wide spacing of sowing rice facilitates development of functional leaves and increase in leaf area and number of tillers, which in turn increases photosynthetic rate leading to taller plants (Shrirame et al., 2000).

The number of tillers increased with an increase in nitrogen application (Tables 6 and 7). The number of tillers increased continuously in all stages with the highest being 15 and 20 recorded under 120 kg N ha^{-1} and SRI × 90 kg N ha^{-1} during wet and dry seasons, respectively. The number of tillers recorded under SRI was higher than that under CP. This is due to nitrogen application, which played role in cell division and elongation of various basal internodes of rice stems leading to increased plat height (Mboyerwa et al., 2021; Zhang et al., 2020; Mazumder et al., 2019). The increase in number of tillers could be associated with the wide spacing (less competition for the growth resources), aeration due to wetting and drying cycles, and root volume that has enhanced nutrients use and yield increase. The increase in number of tillers and height of plants under SRI has been reported by other studies (Kangile et al., 2018; Reuben et al., 2016; Kahimba et al., 2013; Katambara et al., 2013). The reduced number of tillers in plant under CP could be due to narrow environment, high plant density per hill with high competition for nutrients, and light energy.

3.2.1. *Chlorophyll content*

Chlorophyll content (CC) was significantly ($p < 0.05$) affected by the crop management practice (CMP) at panicle initiation stage, with high CC (9%) recorded under SRI plants compared with in plants under CP (Table 8). The significant effect of N levels on CC was recorded at panicle

Table 12. Effects of crop management practices and fertilizer N levels on effective and non effective tillers, filled and un filled panicles and grains filling rate.

Parameter	Effective tillers hill-1		Non effective tillers hill-1		Filled grains panicle-1		Unfilled grains panicle-1		Grains filling rate (%)	
Season	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS
Crop management practices (CMP)										
SRI	12.8	13.5	1.7	0.6	127.1	114.2	18.8	39.3	87.1	74.5
CP	8.1	9.6	1.0	1.3	94.5	60.9	18.9	25.9	83.3	70.1
LSD 0.05	1.095	2.46	0.609	NS	16.19	51.74	NS	NS	2.54	NS
F Pr.	<.001	0.021	0.044	0.118	<.001	0.047	0.937	0.228	0.006	0.579
Nitrogen levels										
ABC	7.3a	8.7a	1.2	0.03	96.2	82.1	21.8	20.7a	80.6	79.2
0 N	8.5a	9.2a	0.4	0.7	105.1	76.2	14.7	24.4ab	87.9	75.0
60 N	11.0b	12.2b	1.7	1.3	105.2	95.1	17.8	43.1c	85.5	69.0
90 N	11.6b	13.7b	1.6	0.8	117.6	102.6	18.8	40.7c	85.8	69.9
120 N	11.8b	13.3b	1.8	1.1	125.6	77.7	20.5	29.9abc	85.9	70.0
150 N	12.4b	12.1b	1.4	2.0	115.4	91.6	19.6	37.1bc	85.4	70.6
LSD (0.05)	1.897	2.577	NS	NS	NS	NS	NS	13.24	NS	NS
F Pr.	<.001	0.002	0.108	0.419	0.327	0.21	0.402	0.01	0.052	0.219
Interaction (CMP x N)										
ABC	8.3ab	8.3	1.3abc	0.0	114.7	98.1	20.4	20.4	84.2	83.3
0 N	10.1b	11.8	0.3a	1.1	122.1	95.4	16.2	30.7	88.7	74.5
SRI 60 N	14.7c	15.3	1.3abc	1.4	121.0	116.2	21.0	52.3	85.1	69.4
90 N	15.1c	17.1	2.7c	0.5	142.5	146.7	20.3	52.4	87.5	73.1
120 N	13.8c	13.9	2.8c	1.1	143.6	101.7	21.5	33.7	87.4	74.1
150 N	15.1c	14.3	1.7abc	2.0	118.9	127	13.3	46.6	89.4	72.7
ABC	7.0a	9.1	1.1abc	0.1	77.7	66.1	23.1	21.0	77.0	75.1
0 N	6.9a	6.7	0.5ab	0.2	88.0	57.1	13.1	18.1	87.1	75.5
60 N	7.3ab	9.1	2.2bc	1.2	89.4	57.1	14.6	33.9	85.9	68.6
CP 90 N	8.1ab	10.3	0.6ab	1.2	92.6	58.4	17.3	28.9	84.1	66.7
120 N	9.3ab	12.7	0.8ab	1.6	107.7	53.6	19.5	26	84.5	65.9
150 N	9.7ab	9.9	1.1abc	3.7	111.9	56.3	25.9	27.7	81.3	68.5
LSD (0.05)	2.683	3.515	1.492	NS	NS	NS	NS	NS	NS	NS
F Pr.	0.021	0.041	0.043	0.295	0.743	0.184	0.117	0.468	0.305	0.865

Mean values followed by different letters denote significant ($P < 0.05$) difference between treatments by DMRT.
NS: not significant.

initiation and milk stages. Significant interaction effects of treatments were observed at panicle initiation stage, although the highest CC (50.4) was recorded at milk stage with an application of 150 kg N ha^{-1}. High CC with SRI plants was attributed to high root-oxidizing activity of the widely-spaced rice plants that improved N uptake (Mishra and Salokhe, 2010). Thakur et al. (2010) reported that the canopies in SRI plants had the highest leaf area index (LAI) and light interception. These characteristics contribute to the maintenance of high chlorophyll levels, enhanced fluorescence and photosynthesis rates of leaves and supported more favourable yield attributes and grain yield in individual hills (Thakur et al., 2010). Hidayati and Anas (2016) reported the improvement in vegetative and generative growth of rice plants under SRI due to increased photosynthesis rate, high chlorophyll content, and increased nutrient uptake and grain yield.

3.2.2. *Root growth characteristics*

The SRI practices affected root characteristics significantly ($p < 0.05$) (Table 9). Results showed that fresh weight, length, and volume of roots per hill were significantly affected by the practices, with the effect of SRI being higher than that of CP. Root dry weight per hill was 55% higher under SRI compared with CP. Nitrogen levels affected root dry weight significantly and higher (13.0 g) dry weight was recorded with an application of 150 kg N ha^{-1}. Interaction effects showed that higher root dry weight per hill (15.2 g) was recorded under SRI × 150 kg N ha^{-1}, although the effect was not significant from other treatments.

Root enhancement facilitates other physiological processes in plants (Thakur et al., 2013; Naher et al., 2009). These include increases in concentrations of cytokinin in roots and shoots. Root oxidation activities, leaf photosynthetic rates, as well as in the activities of key enzymes involved in sucrose-to-starch conversion in grains. The SRI plants form profuse root systems, with little or late senescence, which enhances the opportunity for beneficial interactions of soil microbes. In addition, this enables plant roots to extend their feeder roots to the lower horizons and take up nutrients throughout their life cycle. Chen et al. (2017) reported increased K^+ concentration in shoots and grains in SRI plants compared with the plants grown under continuous flooding practice. Hazra and Chandra (2016) reported that at flowering 78% of the root growing under anaerobic soil conditions undergo degeneration while few of the rice roots growing under aerobic soil conditions were affected. Thakur et al. (2013) found the increase of up to 66% in dry weight per hill compared with transplanted flooded rice at the flowering stage. Enhanced root development in alternate wetting and moderate drying soil water regimes was reported in other studies using SRI practice (Thakur et al., 2011; Zhang et al., 2009). The double increase in root dry weight of rice under SRI compared with the continuous flooding environment was also reported by Ndiiri et al. (2012).

3.3. *Yield and yield components*

Grain yield of rice under SRI was significantly ($p < 0.05$) higher than that of plants under CP at all levels of N application (Table 10). The highest average rice grain yield was found in the SRI treatments (6.7 and 6.4 t ha^{-1}). These values were 10.7 and 34% higher than those of the CP (6.4 and 4.2 t ha^{-1}) during wet and dry seasons, respectively. An

Table 13. Effect of crop management practices and nitrogen levels on agronomic N use efficiency, partial factor productivity and nitrogen contribution rate.

Parameter	ANUE (kg grain kg $^{-1}$N)		PFP_N (kg grain kg^{-1}N)		FCR_N (%)	
Season	WS	DS	WS	DS	WS	DS
Crop establishment method (CEM)						
SRI	21.3	12.03	64.3	58.89	27	17.7
CP	13.3	13.8	54.7	39.76	18	27.5
LSD (0.05)	NS	NS	4.55	7.181	NS	NS
SE	3.9	2.688	1.53	2.417	5.22	3.38
Nitrogen levels (N)						
0 N	-	-	-	-	-	-
60 N	27.2b	19.3b	109.4	88.89c	23.3	22.7
90 N	24.4b	23.8b	79.3	70.23b	29.8	33.4
120 N	19.7b	10.6a	60.8	47.15a	31.0	25.5
150 N	15.1a	11.1a	48.0	40.36a	28.3	31.5
LSD (0.05)	18.33b	12.63	7.20	11.354	NS	15.87
SE	6.17	4.25	2.42	3.82	8.26	5.34
Treatment Interaction (CEM x N)						
SRI0 N	-	-	-	-	-	-
SRI60 N	32.8	17.08	116.7f	105.8d	28.3	16
SRI 90 N	33.7	25.83	89.6d	85.0c	37.2	28.6
SRI120 N	19.7	7.08	61.7bc	55.1b	31.5	17.8
SRI150 N	20.2	10.17	53.8b	48.6	37.7	26.2
CP0 N	-	-	-	-	-	-
CP60 N	21.7	21.53	102.2e	71.94c	18.3	29.4
CP 90 N	15.2	21.85	68.9c	55.46b	22.5	38.1
CP120 N	19.7	14.03	60.0bc	39.24ab	30.4	33.3
CP150 N	10.0	12.0	42.2a	32.17a	18.8	36.7
LSD (0.05)	NS	NS	10.18	16.057	NS	NS
SE	8.72	6.012	3.43	5.404	11.67	7.55

Mean values followed by different letters denote significant ($P < 0.05$) difference between treatments by DMRT.
NS: not significant.

application of N increased rice grain yields over the zero-N and absolute control in the two cropping seasons. Rice grains yield increased with an increase in N levels. However, rice grain yields did not show any further different increase with applications of 120 and 90 kg N ha^{-1} in wet and dry seasons, respectively.

On average, rice grain yields under SRI increased by 16.2% and 55.6% during wet and dry seasons, respectively for all levels of N application. The maximum rice grain yield under SRI was 8.1 t ha^{-1} with applications of 120 and 150 kg N ha^{-1} in wet season and 7.7 tha^{-1} with 90 kg N ha^{-1} in dry season. The maximum rice grain yield under CP was 7.2 t ha^{-1} with an application of 120 kg N ha^{-1} in wet season and 5.0 t ha^{-1} with 90 kg N ha^{-1} in dry season. The quantities of rice grain yields achieved under CP with applications of 90–120 kg N ha^{-1} in dry season were equivalent to the yields achieved with an application of 60 kg N ha^{-1} under SRI. The findings of the present study indicated that rice grain yield was affected by the crop management practices on one side and nitrogen application but the effect is inseparable. Furthermore, the average rice grain yield achieved under SRI is within the range of potential yield (7–8 t ha^{-1}) for rice variety TXD 306. The results of the present study are in agreement with previous studies conducted elsewhere (Mati et al., 2021; Thakur et al., 2021; Sandhu et al., 2017; Reuben et al., 2016; Kahimba et al., 2013; Ashraf et al., 1999). Yang et al. (2007) reported increasing rice yield in SRI plants by approximately 10% relative to continuous flooding. Thakur et al. (2014) found overall grain yield with SRI to be 49% higher than with CP, with yield enhanced at every N application. Other studies have also reported an increase in rice grain yields under SRI practices relative to CP Islam et al. (2020); Sato and Uphoff (2007).

The CMP significantly affected straw yield during dry season and SRI recorded increased yield by 33.3% over CP (Table 10). Straw yield increased with increase in N levels in wet and dry seasons. The highest straw yield was recorded in wet season (6.6 and 6.5 t ha^{-1}) in an application of 150 kg N ha^{-1}, and with interactions of SRI and CP with 150 kg N ha^{-1}. Harvest index (HI) was significantly affected by N levels during wet season, whereas the lowest HI of 0.5 was recorded in an application of 150 kg N ha^{-1}. There was no interaction effects observed between treatments on the straw yields. Results also indicated that the dry weight of 1000-grains was significantly affected by CP in wet season. However, there was no significant effect of N levels or their interactions with CP or SRI observed on the dry weight of 1000 grains. Crop management practices significantly affected panicle weight and spikelets per panicle in wet and dry seasons, with higher values recorded under SRI (Table 11).

The number of panicles per hill was significant with SRI recording 37% and 22% higher than the CP in wet and dry seasons. Nitrogen levels and interactions with SRI or CP significantly affected the number of panicles. The higher panicle weight percentages of 22.2 and 43.6% were recorded under SRI in wet and dry seasons, respectively. Panicle weight increased with an increase in N levels but not beyond 120 kg N^{-1} in wet season and 90 kg N ha^{-1} dry season. Panicle length was significantly ($p < 0.05$) affected by N levels and the length increased with increasing N levels in wet season.

The number of panicle per hill was significantly ($p < 0.05$) affected by crop management practices in wet season, with SRI recording higher number of panicle per hill (15) compared with CP (9). Nitrogen levels and their interactions with SRI or CP significantly affected the number of panicles per hill. Spikelets per panicle were significantly influenced by crop management practices, with SRI recording higher number of spikelets per panicles in wet and dry seasons. Nitrogen levels also significantly affected the number of spikelets per panicle during dry season. Effective tillers were significantly affected by CP, N levels and their interactions ($p < 0.05$) in wet and dry seasons but SRI recorded higher effective tillers over CP (Table 12). The filled grains per panicle were significantly affected by crop management practices ($p < 0.05$) in wet and dry seasons. Grain filling rate was significantly affected by crop management practices in wet season, with increased grain filling by 4.6 and 5.9% under SRI compared with CP in wet and dry season, respectively. There was significant effect of N levels in dry season. Previous studies have reported absence of significant effect of crop management practices on percentage of filled grains (Zheng et al., 2020; Belder et al., 2004).

3.4. Nitrogen use efficiency

An application of N recorded significant effect ($p < 0.05$) on agronomic N use efficiency (ANUE) (Table 13). The ANUE and PFP were decreased by N application levels under SRI and CP in wet and dry seasons. The similar trend of treatments effect on the ANUE and PFP was reported by other researchers (Djaman et al., 2018; Zhao et al., 2009). The ANUE ranged from 19.7–33.7 kg grain kg^{-1} N in wet season to 7.08–25.83 kg grain kg^{-1} N in dry season under SRI. Under CP, the ANUE ranged from 10.0–21.7 kg grain kg^{-1} N in wet season to 12.0–21.85 kg grain kg^{-1} N in dry season. The highest ANUE was recorded with the application of 90 kg N ha^{-1} under SRI and CP in wet and dry seasons (Table 13). The findings of the present study are in agreement with the other studies (Zhang et al., 2020; Djaman et al., 2018; Thakur et al., 2013; Zhao et al., 2009). Other researchers reported low NUE in farmers' fields in different parts of the world (Peng et al., 2002; Cassman and Pingali, 1996).

Partial factor productivity (PFP) was significantly ($p < 0.05$) affected by crop management practices, with N levels and their interactions with SRI and CP. Results indicated that SRI recorded PFP values ranging from 53.8 to 116.7 kg grain kg^{-1} N and 48.6 to 105.8 during wet and dry seasons, respectively. The PFP obtained under CP ranged from 42.2 to 102.2 kg grain kg^{-1} N and 32.17–71.94 kg grain kg^{-1} N during wet and dry seasons, respectively. The highest PFP was found with the application of 60 kg N ha^{-1} under SRI and CP in wet and dry seasons. However, there was a decrease in PFP with N levels exceeding 60 kg N ha^{-1} and with interactions of N and SRI or CP.

Nitrogen levels significantly affected FCR_N during the cropping seasons. The maximum FCR_N was 38.1% and the lowest was 16% recorded under CP × 150 N and SRI × 60 N, respectively. Alternate wetting and drying under SRI could be the reason for the improved oxygen supply to rice roots, thereby decreasing aerenchyma formation. This also caused strong and health root system, with potential advantages for higher nutrients uptake (Hazra and Chandra, 2016). Furthermore, drying and re-watering cycles affect biochemical and physical processes, including nitrification, denitrification, mineralization, percolation, and leaching in soils by changing water and air equilibrium, which in turn affect the availability of nitrogen nutrition (Hazra and Chandra, 2016).

The findings of the present study are in agreement with Thakur et al. (2013) that N use-efficiency and partial factor productivity from applied N were significantly higher in SRI than transplanted flooded rice plants. Espiritu and Javier (2013) reported the PFP values ranging from 65.7 to 414.0 kg grain kg N^{-1} N. Zhu et al. (2016) reported rice PFPN that ranged from 26.9 to 69.1 kg grain kg^{-1} N. Yang et al. (1999) reported that the highest PFPN was achieved under moderate alternate wetting and drying treatments.

4. Conclusion

This field study indicates that nitrogen use efficiency in rice can be met under the system of rice intensification (SRI) management practice due to profuse root development and improved physiological performance. The system results in enhanced grain yield compared with the conventional practice. This indicates that there are systematic interactions between lower plant density (single seedling per hill) in combination with alternate wetting and drying (water saving irrigation) and/or N fertilization. Potential grain yield and higher NUE could be achieved by decreasing N application levels in SRI from 150 to 60 kg N ha^{-1}. An additional benefit derived from SRI is a significant reduction in the costs related to fertilizer inputs and a translation of the same to environmental conservation from population.

Declarations

Author contribution statement

Primitiva Andrea Mboyerwa: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Kibebew Kibret; Abebe Aschalew: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Peter Mtakwa: Performed the experiments; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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