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Growth indices of direct-seeded rice (*Oryza sativa* L.) as influenced by STCR based integrated nutrient management

Saroj Choudhary, SS Baghel, AK Upadhyay, Arjun Singh, Mukta Rani and Sunita Choudhary

Abstract
An experiment was conducted during the *Kharif* seasons of 2016 at the soil science research farm of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.) to study the physiological growth and yield response of direct-seeded rice grown under combined application of fertilizers and manure according to targeted yield and STCR approach. The results revealed that growth indices like leaf area index (3.99), leaf area duration (42.90 days), crop growth rate (19.71 g m^{-2} day^{-1}), relative growth rate (0.0642 g g^{-1} day^{-1}), and net assimilation rate (0.086 g day^{-1} m^{-2}) were higher with the application of 157:125:70 kg N, P_2O_5 and K_2O with 5 t FYM ha^{-1}. Grain and straw yield (5725 and 7623 kg ha^{-1} respectively) was found to be highly significant with the integrated use of fertilizers and manures (T_6).

Keywords: Fertilizers and manure, STCR, Growth indices, LAI, CGR, NAR, Rice

Introduction

Rice (*Oryza sativa* L.) is a staple food for millions of people, providing roughly 700 calories per person per day for about 3000 million people, the majority of whom live in developing nations (Singh *et al*., 2017) [21]. It has influenced the cultures, cuisines, and economies of billions of people all over the world (Farooq *et al.*, 2009) [5]. Paddy is a primary food crop in South, Southeast, and East Asia, which shares about 90% of global paddy production and consumption. To achieve food security, India must increase food grain output to 450 million tonnes (mt) by the end of 2050, which implies the country must add 166 mt to its current production level of 284 mt. (MoAFW, 2018) [15]. In India, rice accounts for over 43% of the country's food grain basket. This announces the addition of rice to the country's food supply to meet the needs of the country's starving people. Rice yield is influenced by a variety of factors including genotype, edaphic, climate, and management. One of the reasons for India's decreased or stagnant rice yield is the unbalanced fertilization of major nutrients (Reddy and Ahmed, 2000) [19]. Fertilizer is one of the most significant and costly inputs in agriculture, and applying the right amount of fertilizer is the most crucial factor in ensuring agricultural profitability and environmental safety (Kimetu *et al.*, 2004) [12]. Fertilizers are routinely applied to crops in India based on generalized state-level fertilizer recommendations, even though crop nutrient requirements vary greatly from place to place, even for the same crop, due to the chemical characteristics of soils, which are very variable. Fertilization of crops based on generic recommendations results in under-fertilization or over-fertilization, lowering production and profitability while also polluting the environment. Among the different techniques of fertilizer recommendation, target yield is unusual in that it not only provides the soil test-based fertilizer dose, but also the level of yield the farmer can expect assuming proper agronomic practices are being followed in crop production (Regar and Singh, 2014) [20].

Troug (1960) [24] was the first to propose fertilizer recommendations based on targeted yield, which was later amended by Ramamoorthy *et al.*, (1967) [17] to fit the Indian situation. It establishes an empirical basis for balanced fertilization and a balance between applied and available nutrients in the soil (Ramamoorthy and Velayutham, 2011) [16]. Application of plant nutrients based on soil tests aids in understanding higher recovery ratios and benefits: cost, because nutrients are provided in proportion to the level of nutrient shortage, and nutrients imbalance in the soil is corrected, the synergistic effects of balanced fertilization can be harnessed. (Rao and Srivastava, 2000) [18]. The present investigation aimed to study the effect of STCR based fertilizer and manure application on the growth and yield of rice.

Growth indices are the real indicators of plant response to different management which we have presented here.

Materials and methods

Experimental site

The current study was done between July to December 2016 at the soil science research farm of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, India, to determine the impact of STCR-based fertilizer and manure application on direct-seeded rice growth and yield. The soils are *typic haplusterts* very deep, colour ranges from dark brown to black (10YR3/1). The soil was clay to loam having pH of 7.57 with organic matter of 0.54%. The detailed initial soil properties are presented in table 1.

Table 1: Initial soil properties of experimental soil

Particulars	Value	Method
Soil pH (pH $_w$ 1:2.5 at 25 ^{0}C)	7.57	Glass electrode pH meter (Jakson, 1973)
Electrical Conductivity (dS m^{-1} at 25 ^{0}C)	0.321	Electrical conductivity meter (Jakson, 1973)
Organic Carbon (g kg^{-1})	5.41	Potassium dichromate rapid titration method (Walkley and Black, 1934)
Available Nitrogen (kg ha^{-1})	217.83	Alkaline permanganate method (Subbiah and Asija, 1956)
Available Phosphorus (kg ha^{-1})	21.45	0.5 M $NaHCO_3$ method (Watanabe and Olsen`s, 1965)
Available Potassium(kg ha^{-1})	311.57	NH_4OAC method (Hanway and Heidel, 1952)

Experimental details

The experiment was conducted in a randomized complete block design (RCBD) with six treatments and replicated four times to reduce errors.

The treatments consisted of the following

T_1: Control
T_2: General recommended dose (120:60:40 kg N, P_2O_5 and K_2O ha^{-1})
T_3: Targeted Yield 50 q ha^{-1} (115:90:49 kg N, P_2O_5 and K_2O ha^{-1})
T_4: Targeted Yield 60 q ha^{-1} (157:125:70 kg N, P_2O_5 and K_2O ha^{-1})
T_5: Targeted Yield 50 q ha^{-1} with 5 t FYM ha^{-1} (115:90:49 kg N, P_2O_5 and K_2O with 5 t FYM ha^{-1})
T_6: Targeted Yield 60 q ha^{-1} with 5 t FYM ha^{-1} (157:125:70 kg N, P_2O_5 and K_2O with 5 t FYM ha^{-1})

Fertilizer adjustment equations for rice

$$FN = 4.25\,T - 0.45\,SN$$
$$FP_2O_5 = 3.55\,T - 4.89\,SP$$
$$FK_2O = 2.10\,T - 0.18\,SK$$

FN = Fertilizer nitrogen (kg ha^{-1})
FP_2O_5 = Fertilizer phosphorus (kg ha^{-1})
FK_2O = Fertilizer potassium (kg ha^{-1})
T = Desired yield target (q ha^{-1})
SN = Available soil nitrogen (kg ha^{-1})
SP = Available soil phosphorus (kg ha^{-1})
SK = Available soil potassium (kg ha^{-1})

Full doses of phosphorus, potassium and half dose of nitrogen as per treatment were applied as basal. The remaining half amount of nitrogen was top-dressed in two split doses at 30 and 60 days after sowing. The plot size was 5 m x 5 m and rice variety *Kranti* was used as a test crop. The rice seeds were directly seeded with 25 X 10 cm spacing. The weed plants were eradicated manually soon after germination. The following observations were recorded to analyse the morphological advancement of rice crop.

Leaf area index

Five plants were randomly selected from each plot and the leaf area index (LAI) was determined through the length-width method:

Leaf area = Leaf length x width x K

Where K = adjustment factor i.e. 0.75.

Leaf area $hill^{-1}$ = Total leaf area of middle tiller x Total number of tillers (Yoshida *et al*., 1976) [29].

The LAI was calculated by the following formula (Watson, 1947).

$$LAI = \frac{\text{Leaf area hill}^{-1}}{\text{Land area hill}^{-1}}$$

Leaf area duration

Leaf area duration measures the ability to produce leaf area on unit land throughout its life. The leaf area duration (LAD) was estimated according to Hunt (1978) [10] in days.

$$LAD = \frac{(LAI_2 + LAI_1)\,(t_2 - t_1)}{2}$$

Where, LAI_1 and LAI_2 are the leaf area index at times t_1 and t_2, respectively.

Crop growth rate (CGR)

The daily increment in biomass is termed as the crop growth rate (CGR) and was determined at different growth stages (30, 60 and 90 DAS) by using the formula as suggested by Watson (1952) and it is expressed in g m^{-2} day^{-1}.

$$CGR = \frac{W_2 - W_1}{p(t_2 - t_1)}$$

Where, W_1 - dry weight per unit area at t_1, W_2 - dry weight per unit area at t_2, p -ground area (m^2), t_1 - first sampling time and t_2 - second sampling time (days).

Relative Growth rate (RGR)

The RGR expresses the dry weight increase in the time interval to the initial weight. It was determined at different growth stages (30, 60 and 90 DAS) by using the formulae as suggested by Blackman (1919) and it is expressed in g g^{-1} day^{-1}.

$$RGR = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

Where

$\log_e$ - Natural log, W_1 - dry weight per unit area at t_1, W_2 - dry weight per unit area at t_2, t_1 - first sampling time and t_2 - second sampling time.

Absolute Growth Rate (AGR)

It expressed the dry weight per unit time and expressed in g plant^{-1} day^{-1}. It was determined in 30 days interval (30, 60 and 90 DAS) by using the formula:

$$CGR = \frac{W_2 - W_1}{t_2 - t_1}$$

Where, W_1 - dry weight per unit area at time t_1, W_2 - dry weight per unit area at time t_2, t_1 - first sampling time and t_2 - second sampling time.

Net assimilation rate (NAR)

The net assimilation rate (NAR) is the net gain of assimilates per unit leaf area and time. It is estimated in g m^{-2} day^{-1} by using the following formula:

$$NAR = \frac{(W_2 - W_1)(\log_e LA_2 - \log_e LA_1)}{(t_2 - t_1)(LA_2 - LA_1)}$$

Where, W_1- dry weight per unit area at t_1, W_2 - dry weight per unit area at t_2, $\log_e LA_1$- Natural log of leaf area at time t_1, $\log_e LA_2$- Natural log of leaf area at time t_2.

Statistical analysis

The collected experimental data were statistically analysed using Fisher's method of analysis of variance, as described by Gomez and Gomez (1984) [7]. In the F test, the level of significance was set at 5%.

Result and Discussion

Leaf area index

The leaf area index (LAI) is a crucial plant growth indicator that describes how well crops can capture solar energy for biomass production, the quantity of plant transpiration, and how crop management strategies affect crop growth. The leaf area index of rice caused significant improvement by fertilizers with and without FYM, have increased successively as the growth progressed up to 60 DAS and thereafter it declined at 90 DAS due to drying of leaves (Table 2). The maximum leaf area index (1.26, 4.12, and 4.47 at 30, 60 and 90 Days respectively) was observed with treatment T_6 (157:125:70 kg N, P_2O_5 and K_2O with 5 t FYM ha^{-1}) followed by treatment T_5 (115:90:49 kg N, P_2O_5 and K_2O with 5 t FYM ha^{-1}) at all the stages which was showing that combined application of fertilizer and manure affect more to leaf area index as compare only fertilizer application. The minimum leaf area (0.98, 3.02, and 3.11 at 30, 60, and 90 days respectively) was observed with control treatment where neither fertilizer nor manure was applied. Earlier, Barik and Fulamli (2011) [2] have reported that the incorporation of nutrients at lower and higher doses of inorganic ones (20 kg N + 40 kg P_2O_5 + 20 kg K_2O ha^{-1} or 40 kg N + 60 kg P_2O_5 + 40 kg K_2O ha^{-1}) significantly improved the LAI at 30, 60 and 90 DAS. Further, Kumar *et al.* (2005) reported that application of 120 kg N + 26.2 kg P_2O_5 + 33.2 kg K_2O ha^{-1} along with 10 t FYM ha^{-1} recorded a significantly higher leaf area index over the rest of the treatment combinations.

Table 2: Leaf area index of rice under different nutrient management

Treatments	Leaf area index		
	30 DAS	60 DAS	90 DAS
T_1: Control	0.98^b	3.02^d	3.11^d
T_2: GRD	1.19^a	3.51^c	3.77^c
T_3: T.Y. 50 q ha^{-1}	1.21^a	3.66^{bc}	3.93^{bc}
T_4: T.Y. 60 q ha^{-1}	1.22^a	3.72^{bc}	3.99^{bc}
T_5: T.Y. 50 q + 5 t FYM ha^{-1}	1.25^a	3.91^{ab}	4.23^{ab}
T_6: T.Y. 60 q + 5 t FYM ha^{-1}	1.26^a	4.12^a	4.47^a
CD (p=0.05)	0.12	0.34	0.41

*T.Y.- Targeted Yield

Leaf Area Duration

Leaf area duration provides a means for comparing treatments based on their leaf persistence. It is usually determined by measuring the area beneath the leaf growth curve for selected parts of the season. The application of fertilizers with or without FYM influences the leaf area duration (Table 3). Between 30-60 day after sowing, the maximum leaf area duration (42.90) was recorded in T_6 (157:125:70 kg N, P_2O_5 and K_2O with 5 t FYM ha^{-1}) which was higher to T_1, T_2, T_3 and T_4. However, it was at par with T_5 (39.90). At 60-90 DAS, leaf area duration was decreased, however, it has also followed a similar trend.

Table 3: Leaf area duration of rice under different nutrient management

Treatments	Leaf Area Duration (days)	
	30-60 DAS	60-90 DAS
T_1: Control	30.60^d	1.35^b
T_2: GRD	34.80^c	3.90^a
T_3: T.Y. 50 q ha^{-1}	36.75^{bc}	4.05^a
T_4: T.Y. 60 q ha^{-1}	37.50^{bc}	4.05^a
T_5: T.Y. 50 q + 5 t FYM ha^{-1}	39.90^{ab}	4.80^a
T_6: T.Y. 60 q + 5 t FYM ha^{-1}	42.90^a	5.25^a
CD (p=0.05)	3.98	0.53

*T.Y.- Targeted Yield

Crop growth rate

Crop growth rate (CGR) was varied significantly by different treatments at all the stages of crop growth with increasing levels of NPK incorporated with and without FYM (Table 4). CGR was increased gradually with the advancement of growth stages up to 60 DAS, but a rapid increment rate was recorded during 30 to 60 DAS and thereafter it declined at 90 DAS. The maximum crop growth rate (19.71 g m^{-2} day^{-1}) was observed between 30- 60 days after sowing in treatment T_6 where 157:125:70 kg N, P_2O_5 and K_2O with 5 t FYM ha^{-1} was applied followed by treatment T_4 where the same amount of fertilizer was applied but without FYM. The minimum crop group rate was observed in the control (T_1). The increase in crop growth rate is due to the integration of inorganic nutrients with organic manure, which might have increased the nutrient availability in synchronisation with crop nutrients demand. LAI was also increased with increasing NPK level which favoured enhanced photosynthetic activity in plants, and explains the higher CGR. The increase in CGR ultimately increases total dry matter at the end of the growing season. Gulser, (2005) [8] reported that high nitrogen levels increased leaf area, leaf number and vegetative growth of plants thus increasing the photosynthetic capacity; consequently, the higher dry matter produced increasing crop growth rate (CGR).

Table 4: Crop growth rate (g m^{-2} day^{-1}) of rice under different nutrient management

Treatments	Crop growth rate (g m^{-2} day^{-1})	
	30 -60 DAS	60-90 DAS
T_1: Control	12.13^{d}	2.72^{e}
T_2: GRD	14.77^{c}	4.69^{d}
T_3: T.Y. 50 q ha^{-1}	16.12^{bc}	5.49^{c}
T_4: T.Y. 60 q ha^{-1}	18.08^{ab}	6.24^{ab}
T_5: T.Y. 50 q + 5 t FYM ha^{-1}	17.81^{ab}	5.79^{bc}
T_6: T.Y. 60 q + 5 t FYM ha^{-1}	19.71^{a}	6.39^{a}
CD (p=0.05)	1.99	0.56

*T.Y.- Targeted Yield

Relative crop growth rate

The Relative Growth Rate (RGR) takes into consideration the original differences in plant size, which can have a substantial impact on the growth in dry mass, as well as the differences in plant performance as they age. The application of relative growth rates, which involves analysing plant growth in relation to plant size, has evolved more or less independently in different research groups and at different times, and has provided significant tools for evaluating plant growth performance and efficiency. The results of the experiment showed that relative crop growth rate influenced with the application of fertilizers and manure application. The RGR was found to be non-significant between 30-60 DAS however it was significant at 60-90 DAS (Table 5). The maximum RGR (0.0086 g g^{-1} day^{-1}) was observed in treatment T_4 (147:117:64 kg N:P_2O_5:K_2O ha^{-1}) followed by T_6 and T_5 which were found similar (0.0086 g g^{-1} day^{-1}) and the minimum was observed with control treatment.

Table 5: Relative Growth Rate (g g^{-1} day^{-1}) of rice under different nutrient management

Treatments	Relative Growth Rate (g g^{-1} day^{-1})	
	30-60 DAS	60-90 DAS
T_1: Control	0.0613^{a}	0.0058^{b}
T_2: GRD	0.0626^{a}	0.0079^{a}
T_3: T.Y. 50 q ha^{-1}	0.0636^{a}	0.0085^{a}
T_4: T.Y. 60 q ha^{-1}	0.0639^{a}	0.0086^{a}
T_5: T.Y. 50 q + 5 t FYM ha^{-1}	0.0642^{a}	0.0082^{a}
T_6: T.Y. 60 q + 5 t FYM ha^{-1}	0.0649^{a}	0.0082^{a}
CD (p=0.05)	NS	0.001

*T.Y.- Targeted Yield

Absolute Growth Rate

Absolute Growth Rate (AGR), if referred to the size of a plant, represents the increase in its mass per unit of time. Among different treatments (Table 6.) it found maximum in treatment T_6 (0.492 g $plant^{-1}$ day^{-1}) followed by T_4 (0.452 g $plant^{-1}$ day^{-1}) and the minimum was found in treatment T_1 (control). Between 60-90 DAS absolute growth rate was decreased but it was found significant and followed the earlier trend. It increased might be because the application of increased level of fertilizers with or without FYM provides more nutrients to plants and thus it increased the growth rate of the plant.

Table 6: Absolute Growth Rate (g $plant^{-1}$ day^{-1}) of rice under different nutrient management

Treatments	Absolute Growth Rate (g $plant^{-1}$ day^{-1})	
	30-60 DAS	60-90 DAS
T_1: Control	0.303^{d}	0.068^{d}
T_2: GRD	0.369^{c}	0.117^{c}
T_3: T.Y. 50 q ha^{-1}	0.403^{bc}	0.137^{b}
T_4: T.Y. 60 q ha^{-1}	0.452^{ab}	0.156^{a}
T_5: T.Y. 50 q + 5 t FYM ha^{-1}	0.445^{ab}	0.145^{ab}
T_6: T.Y. 60 q + 5 t FYM ha^{-1}	0.493^{a}	0.160^{a}
CD (p=0.05)	0.057	0.017

*T.Y.- Targeted Yield

Net assimilation rate (g day^{-1} m^{-2})

The crop growth rate depends on the two parameters namely: leaf area of the plant and the net assimilation of photosynthates. The Net Assimilation Rate (NAR) of rice was significantly increased with increased application of fertilizers and manure and ranged from 0.056 to 0.086 and 0.022 to 0.031 at 30-60 and 60-90 days intervals, respectively (Table 7). The maximum NAR was 0.086 and 0.031 g day^{-1} m^{-2} in the treatments received 157:125:70 kg N, P_2O_5, and K_2O with 5 t FYM ha^{-1} at 30-60 and 60-90 DAS, respectively. The minimum net assimilation was recorded in control treatment where fertilizers were not applied. Increased in net assimilation rate enhances photosynthetic capacity of leaves with improved nutrition of the plants thereby increasing dry matter accumulation at final harvest (Ahmad *et al*., 1990).

Table 7: Net assimilation rate (g day^{-1} m^{-2}) of rice under different nutrient management

Treatments	Net assimilation rate (g day^{-1} m^{-2})	
	30-60 DAS	60-90 DAS
T_1: Control	0.056^{d}	0.022^{c}
T_2: GRD	0.069^{c}	0.025^{bc}
T_3: T.Y. 50 q ha^{-1}	0.074^{bc}	0.027^{ab}
T_4: T.Y. 60 q ha^{-1}	0.084^{ab}	0.029^{ab}
T_5: T.Y. 50 q + 5 t FYM ha^{-1}	0.081^{ab}	0.028^{ab}
T_6: T.Y. 60 q + 5 t FYM ha^{-1}	0.086^{a}	0.031^{a}
CD (p=0.05)	0.011	0.004

*T.Y.- Targeted Yield

Rice yield

Application of fertilizer with or without FYM based on STCR equation significantly influenced the grain and straw yield of rice (Table 8). The grain and straw yield of rice were found significantly higher in T_6 (5725 and 7623 kg ha^{-1}, respectively) over control. The targeted yield of T_6 (60 q ha^{-1}) could not be achieved and deviated by 4.58% negatively; whereas the targeted yield of T_5 (50 q ha^{-1}) was obtained conveniently. The target grain yield was achieved only in treatment T_5 which was significantly higher over control. Maximum grain yield (5725 kg ha^{-1}) was recorded with the application of 157:125:70 kg N: P_2O_5:K_2O with 5 t FYM ha^{-1}, which was statistically significant with other treatments except for T_4 and T_5, whereas minimum grain yield of 2781 kg ha^{-1} was found under control. The effect of treatments on straw yield also followed a similar trend as that of grain yield. The higher yield of straw (7623 kg ha^{-1}) was obtained with a higher level of inorganic fertilizers along with FYM (T_6), which was significantly superior to control (4295 kg ha^{-1}), T_2 (GRD) and T_3. However, it was statistically at par with T_4 and T_5. Improvement in yield attributes may be ascribed to adequate and regular nutrients supplying capacity of the soil and translocation of nutrients to the sink. The improvement in yield and yield traits under higher level nutrients might be due to higher absorption of nutrients and increased photosynthesis activity leading to higher accumulation of biomass. Similar findings were also reported by Subehia and Sepehya (2012) [23], Gautam *et al.* (2013) [6] and Mahmud *et al.* (2016) [14]. Earlier, Chesti *et al.* (2015) [4] reported that significantly higher grain yield of 5.36 t ha^{-1} with the application of 100% NPK+10 t FYM ha^{-1} as compared to the grain yield of 4.96 t ha^{-1} with the 100% NPK alone.

Table 8: Grain and straw yield of rice under different nutrient management

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1: Control	2781^{d}	4295^{d}
T_2: GRD	4237^{c}	5859^{c}
T_3: T.Y. 50 q ha^{-1}	4819^{bc}	6587^{bc}
T_4: T.Y. 60 q ha^{-1}	5371^{ab}	7235^{ab}
T_5: T.Y. 50 q + 5 t FYM ha^{-1}	5213^{ab}	7051^{ab}
T_6: T.Y. 60 q ha^{-1} + 5 t FYM ha^{-1}	5725^{a}	7623^{a}
CD (p=0.05)	675	963

*T.Y.- Targeted Yield

Conclusion

Based on the results of present investigation and similar finding of previous researchers, it could be concluded that the integrated use of manure with fertilizers based on STCR-Target yield equations, not only higher growth but higher yield could be achieved. There was 105% yield increment was reported in T_6 over the control, which showed the importance of balanced fertilization.

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