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EFFECT OF NAPHTHALENE ACETIC ACID (NAA) ON GRAIN YIELD AND BIOECONOMIC EFFICIENCY OF COARSE RICE (*ORYZA SATIVA* L.)

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Abstract

Plant growth regulators (PGRs) play a pivotal role in plant's life as they coordinate and regulate many physiological processes governing crop growth and yield. Bioeconomic efficiency of a plant growth regulator (NAA 4.5% as sodium salt) on coarse rice (IR-6) was assessed under the agro-ecological conditions of Dera Ismail Khan, Pakistan over two years. The research was conducted in a randomized complete block design (RCBD) with split plot arrangement, repeated four times. Main plots were considered for assessment of three decisive developmental stages of the paddy rice, S_1 (tillering), S_2 (panicle initiation), and S_3 (grain formation stage), while four levels (0, 60, 90 and 120 ml ha^{-1}) of NAA were applied in four sub-plots. The PGR application at different growth stages increased biomass, straw yield and paddy yield (t ha^{-1}) of the paddy rice. Application of NAA @ 90 ml ha^{-1} at the panicle initiation stage caused the highest increase in biomass yield (18.90 and 19.10 t ha^{-1}), paddy yield (8.00 and 8.20 t ha^{-1}), straw yield (12.00 and 12.30 t ha^{-1}), harvest index (42.32 and 42.93%), crop growth rate (28.6 & 32.4 g m^{-2} day^{-1}), photosynthetic efficiency (1.91 and 1.57%), and leaf area index (12.9 and 13.2). Bioeconomic efficiency was also increased (2.09 and 2.16) during both years, respectively. It was concluded from the results so obtained that exogenous application of NAA @ 90 ml ha^{-1} at panicle initiating and tillering stage had been helpful in attaining higher yields in rice with more net returns.

Key words: Rice, Growth stages, Plant growth regulator, Naphthalene acetic acid.

Introduction

Rice (*Oryza sativa* L.) occupies a central position among cereals. In Pakistan, rice is annually cultivated on an area of 2,899 thousand hectares with a total grain production of 7,442 thousand tonnes (Anon., 2018). The rice production in Pakistan is very low as compared to that in other developed countries. Thus, in order to fulfill the consumptive requirements of growing human population, new techniques such as use of exogenous growth regulators are suggested.

Plant growth regulators (PGRs) manipulate the growth and behavioral responses of plants and determine the amount, type and direction of growth as well (Tiwari *et al.*, 2011). Lower concentrations of PGRs may be effective in enhancing the physiological aspects of crops, which ultimately aid in increasing their yield (Sajid *et al.*, 2016). These growth regulators also hasten the assimilate translocation in plants and promote flowering as well (Pandey *et al.*, 2001). Among the growth regulator, auxins, i.e., NAA is responsible for regulating cell division and elongation, adventitious root formation, tissue swelling, promoting cell wall loosening, callus initiation, and growth and induction of embryogenesis (Muthukumar *et al.*, 2007).

Although PGRs are synthesized within the plants, these can also be applied exogenously for achieving high crop yield. The hormones applied can be stored in the form of reversible conjugates by plants and used when these are needed at any site in the plant (Tiwari *et al.*, 2011). When these regulators are externally applied, they govern hormonal pattern inside the plant body by interacting with their synthesis, translocation or by inactivating the existing hormonal levels (Abel & Theologis, 2010). Plant growth regulators play important roles in plant growth and development, but little is known about the roles of the plant growth regulator, NAA, in transplanted paddy yield and the proper stage of its application. In the present study an attempt was made to improve the productivity, harvest index and benefit-cost ratio of the exogenous application of NAA at three critical growth stages of coarse rice.

Materials and Methods

An experiment was conducted with the aim to evaluate the effect of exogenously applied varying doses of naphthalene acetic acid (NAA) on three growth stages of coarse rice IR-6 at the Postgraduate Research Area, Gomal University, Dera Ismail Khan, KPK, Pakistan, during 2016 and 2017. The soil was slightly alkaline (pH 7.7-8.0) with the clay texture. The trial was repeated four times in a RCB-design arranged in split-plot fashion. Main plots were assigned with timing of NAA application at different growth stages of rice, while sub-plots consisted of NAA levels. Each sub-plot was of 15 m^2.

The sub-plot treatments consisted of four doses (0, 60, 90 and 120 ml ha^{-1}) of NAA as 4.5% sodium salt which was applied at three growth stages viz. S_1=tillering stage, S_2= panicle initiation stage, and S_3= grain formation stage. Nitrogen was applied in the form of urea @ 120 kg ha^{-1}, while phosphorus was used in the form of single super phosphate @ 100 kg ha^{-1} (Maqsood *et al.*, 2001). Phosphorus was applied at once at the time of rice seedlings' transplantation, whereas nitrogen was divided into two equal halves, i.e., one half of the nitrogen dose was applied during transplantation, while the rest at the panicle initiation stage. Seeds were disinfected in 0.5% sodium hypochlorite solution. Moreover, the seeds that sank in water were preferred for sowing over those which floated. Paddy seeds were soaked in water for one day (24 hours) and then kept moist under gunny bags for other 36 hours. These seeds were sown on a fine seedbed after they sprouted. The seedlings were transplanted after 35 days by maintaining R-R and P-P distance of 20 cm. After the harvest, data were recorded for various agronomic attributes such as biomass yield (biomass yield t ha^{-1} = biomass yield m^{-2} x 10,000), straw yield (biomass yield minus grain yield), paddy yield (paddy yield t ha^{-1} = paddy yield m^{-2} x 10,000), harvest index (paddy yield x 100/biomass yield following Yaduraju & Ahuja, 1996), leaf area index (leaf length x leaf width x correction factor x number of leaves plant^{-1} x number of plants m^{-2} following Stoskopf, 1981), crop growth rate (W2-W1/ T2-T1 following Yaduraju & Ahuja, 1996), photosynthetic efficiency (%) on dry weight basis (Energy output/Energy input x 100) following Stoskopf (1981), and benefit cost ratio (Total return/ total expenditure). The data so obtained were subjected to the MSTATC computer software for working out analysis of variance of each attribute. To compare the means for significant difference, the LSD test at 5% level of probability was applied.

Results

Biomass yield (t ha^{-1}): Exogenous application of varying levels of naphthalene acetic acid (NAA) used at different growth stages significantly ($p\leq0.05$) increased biomass yield (t ha^{-1}). The effects of the levels of NAA applied at different growth stages on biomass yield were also significant during both years (Table 1). The data in Table 1 showed that the highest biomass yield of 18.90 and 19.10 t ha^{-1} was recorded during 2016 and 2017 years when 90 ml ha^{-1} NAA was applied at the panicle initiation growth stage. In contrast, the lowest biomass yield (13.00 & 14.10 t ha^{-1}) was noted in the coarse rice plants fed with no PGR. The PGR application was found to be the most effective in increasing biomass yield when applied at the panicle initiation growth stage followed by that at the tillering stage. Hence, the most effective dose of NAA application was 90 ml ha^{-1} applied at the panicle initiation stage of rice in producing the maximum biomass during both years.

Straw yield (t ha^{-1}): Statistical analysis of data for straw yield (Table 2) clearly demonstrated that NAA, growth stages and their interaction showed significant ($p\leq0.05$) results during 2016 and 2017. The highest straw yield of 12.00 t ha $^{-1}$ was achieved when NAA was applied @ 90 ml ha $^{-1}$ at the panicle initiation stage (G2 x S2) followed by 10.80 t ha^{-1} at NAA @ 90 ml ha^{-1} at the tillering stage (G2 x S1), while the lowest straw yield of 7.00 t ha^{-1} was observed at NAA @ 120 ml ha^{-1} applied at the grain formation stage (G3 x S3) during the study year 2016. Almost a similar trend was observed during the year 2017 in which maximum straw yield (12.30 t ha^{-1}) was noted at G2 x S2 followed by at G3 x S1 by producing straw yield of 11.00 t ha^{-1}, however, the minimum straw yield of 7.20 t ha^{-1} was obtained at G3 x S3 treatment.

Paddy yield (t ha^{-1}): Yield is the ultimate goal of every agricultural research which in turn is the combined outcome of all the physiological processes carried out in whole plant life. Analysis of the paddy yield data showed significant ($p\leq0.05$) differences among the mean values of grain yield with NAA levels, paddy growth stages and their interaction (Table 3). The data in Table 3 exhibited that NAA applied at the panicle initiation stage @ 90 ml ha^{-1} (G2 x S2) gave the highest paddy yield (8.00 & 8.20 t ha^{-1}) followed by NAA @ 90 ml ha^{-1} applied at the tillering stage (G2 x S1) (7.15 & 7.40 t ha^{-1}), while the lowest paddy yield of 4.62 & 5.00 t ha^{-1} was achieved in NAA applied @ 120 ml ha^{-1} at the grain formation stage G3 x S3) during both years (2016 & 2017).

Harvest index (%): Harvest index (HI %) indicates the percentage of assimilates translocated towards economic yield. Table 4 exhibited the significant ($p\leq0.05$) variation for HI % for the PGR, paddy growth stages and their interactions too. The highest HI (42.32 & 42.93%) was observed for NAA @ 90 ml ha^{-1} applied at the panicle initiation stage (G2 x S2), which was followed by statistically at par with HI (40.85 & 41.57%) in NAA @ 90 ml ha^{-1} applied at the tillering stage (G2 x S1), followed by NAA @ 90 ml ha^{-1} applied at the grain formation stage (G2 x S3) (38.03 & 39.52%), while the minimum HI (35.53 & 35.46&) was noted for NAA @ 120 m ha^{-1} at the grain formation stage (G3 x S3) treatment for both study years.

Leaf area index (LAI): Leaf area index (LAI) is a ratio between total leaf area taken by plants at any time and the land area occupied for crop growth. Leaf area indices presented in Table 5 demonstrated significant ($p\leq0.05$) effect of the PGR, paddy growth stages and their interaction as well. During both years of study (2016 & 2017) almost a similar trend was noted regarding leaf area index. The maximum LAI (12.9 & 13.2) was noted with NAA @ 90 ml ha^{-1} when applied at the panicle initiation stage (G2 x S2) which was closely followed by NAA @ 90 ml ha^{-1} applied at the tillering stage (G2 x S1) by producing LAI of 9.8 & 10.3 during both years of study. While the lowest LAI (5.3) was recorded without NAA application at the grain formation (G0 x S3) during 2016 and LAI of 6.3 with NAA @ 120 ml ha^{-1} at grain formation stage (G3 x S3) treatments during 2017, respectively.

Crop growth rate (g m^{-2} day^{-1}): An important indicator of crop productive capacity is the crop growth rate (CGR). CGR measures the increase in crop biomass per unit ground area per unit time. This measure takes into account both photosynthetic gains and respiratory losses, and other crop architectural attributes that impact photosynthesis, such as crop height, and leaf shape and inclination. Analysis of the data presented in Table 6 showed significant ($p\leq0.05$) effect of NAA, paddy growth stages and their interaction on CGR during both years (2016 & 2017). The maximum increase in CGR (28.6 & 32.4 g m^{-2} day^{-1}) was observed with NAA @ 90 ml ha^{-1} followed by (25.7 & 22.2 g m^{-2} day^{-1}) without NAA applied at the tillering stage, and then followed by at NAA @ 60 ml ha^{-1} applied at the tillering stage (G1 x S1) (23.9 & 20.4 g m^{-2} day^{-1}), whereas the minimum CGR (12.2 & 13.2 g m^{-2} day^{-1}) was measured with NAA @ 120 ml ha^{-1} applied at the grain formation stage (G3 x S3) during both years.

Table 1. Effect of NAA levels on biomass yield (t ha^{-1}) at different growth stages of transplanted coarse rice during 2016-17.

Plant growth regulator	2016				2017			
	Stages				Stages			
	S_1	S_2	S_3	Means	S_1	S_2	S_3	Means
G_0	14.70 G	14.50 G	14.30 G	14.44 D	14.50 H	14.80 GH	14.70 GH	14.67 D
G_1	15.90 E	17.1 BC	15.20 F	16.07 B	16.30 DEF	17.40 BC	15.50 FG	16.40 D
G_2	17.50 B	18.90 A	16.30 DE	17.57 A	17.80 B	19.10 A	16.70 CDE	17.87 A
G_3	15.70 EF	16.70 CD	13.00 H	15.13 C	15.90 EF	17.00 BCD	14.10 H	15.67 C
Means	15.91 B	16.80 A	14.70 C		16.13 B	17.08 A	15.25 C	

Different letter(s) assigned to the mean values in a column show significance at 1% probability level
$LSD_{0.01}$ = 0.73 (Growth stages); $LSD_{0.01}$ = 0.63 (Growth stages); $LSD_{0.01}$ = 0.35 (Plant growth regulator)
$LSD_{0.01}$ = 0.49 (Plant growth regulator); $LSD_{0.01}$ = 0.62 (Interaction); $LSD_{0.01}$ = 0.85 (Interaction)

Table 2. Effect of NAA levels on straw yield (t ha^{-1}) of transplanted coarse rice at different growth stages during 2016-17.

Plant growth regulator	2016				2017			
	Stages				Stages			
	S_1	S_2	S_3	Means	S_1	S_2	S_3	Means
G_0	7.60 GH	7.50 GH	7.20 H	7.43 D	8.00 EF	8.20 EF	7.80 FG	8.00 C
G_1	8.50 EF	9.70 C	8.00 FG	8.73 B	8.70 DE	10.00 C	8.30 EF	9.00 B
G_2	10.80 B	12.00 A	9.30 CD	10.70 A	11.00 B	12.30 A	9.6 C	10.97 A
G_3	8.30 F	9.00 DE	7.00 H	8.10 C	8.60 E	9.40 CD	7.20 G	8.40 C
Means	8.80 B	9.55 A	7.88 C		9.08 B	9.98 A	8.22 C	

Different letter(s) assigned to the mean values in a column show significance at 1% probability level
$LSD_{0.01}$ = 0.61 (Growth stages); $LSD_{0.01}$ = 0.48 (Growth stages); $LSD_{0.01}$ = 0.40 (Plant growth regulator)
$LSD_{0.01}$ = 0.42 (Plant growth regulator); $LSD_{0.01}$ = 0.69 (Interaction); $LSD_{0.01}$ = 0.73 (Interaction)

Table 3. Effect of NAA levels applied at different growth stages on paddy yield (t ha^{-1}) of transplanted coarse rice during 2016-17.

Plant growth regulator	2016				2017			
	Stages				Stages			
	S_1	S_2	S_3	Means	S_1	S_2	S_3	Means
G_0	5.20 EF	5.30 E	5.00 EF	5.17 C	5.40 EF	5.50 DEF	5.20 EF	5.37 C
G_1	6.00 CD	7.00 B	5.50 DE	6.17 B	6.20 CD	7.40 B	5.40 EF	6.33 B
G_2	7.15 B	8.00 A	6.20 C	7.12 A	7.40 B	8.20 A	6.60 C	7.40 A
G_3	5.50 DE	6.30 C	4.62 F	5.48 C	5.80 DE	6.60 C	5.00 F	5.80 C
Means	5.93 AB	6.65 A	5.33 B		6.20 B	6.92 A	5.55 C	

Different letter(s) assigned to the mean values in a column show significance at 1% probability level
$LSD_{0.01}$ = 0.35 (Growth stages); $LSD_{0.01}$ = 0.38 (Growth stages); $LSD_{0.01}$ = 0.35 (Plant growth regulator)
$LSD_{0.01}$ = 0.44 (Plant growth regulator); $LSD_{0.01}$ = 0.61 (Interaction); $LSD_{0.01}$ = 0.76s (Interaction)

Table 4. Effect of NAA levels applied at different growth stages on harvest index (%) of transplanted coarse rice during 2016-17.

Plant growth regulator	2016				2017			
	Stages				Stages			
	S_1	S_2	S_3	Means	S_1	S_2	S_3	Means
G_0	35.37 D	36.55 CD	34.96 D	35.80 B	37.24 BCD	37.16 BCD	35.37 D	36.60 B
G_1	37.73 BCD	40.93 AB	36.18 D	38.39 AB	38.03 ABCD	42.52 AB	34.83 D	38.59 AB
G_2	40.85 ABC	42.32 A	38.03 BCD	40.52 A	41.57 ABC	42.93 A	39.52 ABCD	41.41 A
G_3	35.03 D	37.72 BCD	35.53 D	36.21 B	34.46 CD	38.82 ABCD	35.46 D	37.01 B
Means	37.27 A	39.58 A	36.25 A		38.43 AB	40.51 A	36.39 B	

Different letter(s) assigned to the mean values in a column show significance at 1% probability level
$LSD_{0.01}$ = 3.43 (Growth stages); $LSD_{0.01}$ = 2.69 (Growth stages); $LSD_{0.01}$ = 1.91 (Plant growth regulator)
$LSD_{0.01}$ = 2.64 (Plant growth regulator); $LSD_{0.01}$ = 3.31 (Interaction); $LSD_{0.01}$ = 4.58 (Interaction)

Table 5. Effect of NAA levels at different growth stages on leaf area index ratio of transplanted coarse rice during 2016-17.

Plant growth regulator	2016				2017			
	Stages				Stages			
	S_1	S_2	S_3	Means	S_1	S_2	S_3	Means
G_0	6.5 D	8.2 C	5.3 E	6.67 B	7.4 D	6.4 D	6.5 D	6.77 C
G_1	5.9 E	7.8 C	6.9 D	6.87 B	5.7 E	9.3 B	8.2 C	7.73 B
G_2	9.8 B	12.9 A	11.2 AB	11.3 A	10.3 B	13.2 A	10.7 B	11.37 A
G_3	9.2 B	10.6 B	10.9 B	10.23 A	8.5 C	9.2 B	6.3 D	8.0 B
Means	7.85 B	9.88 A	8.58 AB		7.98 B	9.53 A	7.93 C	

Different letter(s) assigned to the mean values in a column show significance at 1% probability level
$LSD_{0.01}$ = 0.20 (Growth stages); $LSD_{0.01}$ = 0.50 (Growth stages); $LSD_{0.01}$ = 0.73 (Plant growth regulator)
$LSD_{0.01}$ = 0.27 (Plant growth regulator); $LSD_{0.01}$ = 0.16 (Interaction); $LSD_{0.01}$ = 0.20 (Interaction)

Table 6. Effect of NAA levels applied growth stages on crop growth rate (gm^{-2} day^{-1}) of transplanted coarse rice during 2016-17.

Plant growth regulator	2016				2017			
	Stages				Stages			
	S_1	S_2	S_3	Means	S_1	S_2	S_3	Means
G_0	25.7 B	18.2 DE	14.5 F	19.47 B	22.2 B	18.5 D	15.3 F	18.67 C
G_1	23.9 C	18.3 DE	17.6 E	19.93 AB	20.4 C	17.3 D	16.2 E	18.00 C
G_2	28.6 A	20.9 D	22.3 C	23.93 A	32.4 A	18.4 D	16.3 E	22.37 A
G_3	24.8 C	20.4 D	12.2 G	19.13 AB	25.7 B	21.2 C	13.2 G	20.03 B
Means	25.75 A	19.45 B	16.65 C		25.18 A	18.85 B	15.25 C	

Different letter(s) assigned to the mean values in a column show significance at 1% probability level
$LSD_{0.01}$ = 2.80 (Growth stages); $LSD_{0.01}$ = 3.50 (Growth stages); $LSD_{0.01}$ = 0.34 (Plant growth regulator)
$LSD_{0.01}$ = 0.67 (Plant growth regulator); $LSD_{0.01}$ = 0.50 (Interaction); $LSD_{0.01}$ = 0.10 (Interaction)

Table 7. Effect of NAA levels applied at different growth stages on photosynthetic efficiency (%) of transplanted coarse rice during 2016-17.

Plant growth regulator	2016				2017			
	Stages				Stages			
	S_1	S_2	S_3	Means	S_1	S_2	S_3	Means
G_0	1.50	1.23	1.13	1.28 B	1.24	0.96	0.94	1.05
G_1	1.90	1.26	1.20	1.45 AB	1.92	1.41	1.20	1.51
G_2	2.50	1.29	1.11	1.63 AB	2.21	1.31	1.20	1.57
G_3	2.60	1.90	1.23	1.91 A	2.25	1.35	1.13	1.58
Means	2.13 A	1.42 AB	1.17 B		1.91 A	1.26 AB	1.12 B	

Different letter(s) assigned to the mean values in a column show significance at 1% probability level
$LSD_{0.01}$ = 0.25 (Growth stages); $LSD_{0.01}$ = 0.14 (Growth stages); $LSD_{0.01}$ = 0.17 (Plant growth regulator)
$LSD_{0.01}$ = (Plant growth regulator); $LSD_{0.01}$ = (Interaction); $LSD_{0.01}$ = (Interaction)

Photosynthetic efficiency (%): Photosynthetic efficiency is also a ratio between energy output and energy taken by the plants in a unit area, so this ratio was expressed in percentage. The photosynthetic efficiency is the fraction of light energy converted into chemical energy during photosynthesis in green plants. Analysis of the data regarding photosynthetic efficiency is shown in Table 7. It depicted that NAA and paddy growth stages significantly ($p\leq0.05$) affected photosynthetic efficiency, whereas their interaction showed non-significant variation among the treatment means during 2016. The data relating to NAA application exhibited that G3, G2 & G1 had higher and statistically at par photosynthetic efficiency (1.91, 1.63 & 1.45%) than untreated control (G0) (1.28%) while initial two growth stages (S1 & S2) also produced higher photosynthetic efficiency (2.13 & 1.42%) than final grain filling stage (S3) (1.17) during 2016. The data for the year 2017 showed that only the paddy growth stages indicated significant ($p\leq0.05$) variation among the treatment means, while NAA and its interaction with growth stages indicated non-significant effects on photosynthetic efficiency (Table 7). Significantly higher and statistically at par photosynthetic efficiency (1.91 & 1.26%) was demonstrated by the PGR application at the tillering and panicle initiation growth stages (S1 & S2) compared to the PGR application at the final grain filling stage (S3) (1.12%).

Economic analysis and BCR: A benefit-cost ratio (BCR) is a ratio used in a cost-benefit analysis to summarize the overall relationship between the relative costs and benefits of a proposed project. BCR can be expressed in monetary or qualitative terms. If a project has a BCR greater than 1.0, the project is expected to deliver a positive net present value to a firm and its investors. Analyzed data for BCR is presented in Table 8, that indicated significant ($p\leq0.05$) effects of NAA, growth stages and their interaction during both years of research (2016 & 2017). The highest BCR (2.09 & 2.06) with maximum net return (Rs: 189440 & 196440/-) was deliberated in the interaction treatments where NAA was applied @ 90 ml ha^{-1} at the panicle initiation stage (G2 x S2) during both years. This was followed by NAA @ 90 ml ha^{-1} applied at the tillering stage (G2 x S1) by producing BCR of 1.76 with a net income of Rs: 159690/- during the year 2016, whereas during the year 2017, it was followed by that at NAA @ 60 ml ha^{-1} applied at the panicle initiation stage (G1 x S2) by giving a BCR of 1.86 with a net income of Rs: 168455/-. The lowest BCR (0.78 & 0.93) was noted in the treatment NAA @ 120 ml ha^{-1}applied at the grain filling stage (G3 x S3) which gave less than one value for BCR indicating a monetary loss over profit. Hence, this treatment was not recommended at all.

Discussion

The results of the present study indicated that overall foliar application of NAA @ 90 ml ha^{-1} applied at the panicle initiation stage increased the biomass yield t ha^{-1} of transplanted coarse rice as compared to all other interaction treatments during both years of study (Table 1). Hormones are known to regulate physiological processes and synthetic growth regulators may enhance growth and development of field crops thereby increasing total dry mass of a field crop (Das & Das, 1996; Abd-el-Fattah, 1997; Chibu *et al*., 2002; Dakua, 2000; Islam, 2007; Cho *et al*., 2007). This might be due to the fact that proper dose of NAA (90 ml ha^{-1}) at the panicle initiation stage caused the rapid cell elongation and division of all the growing parts of rice (leaves, stem, tillers, etc.), resulting in larger size plants with maximum biomass yield per unit area. Jahan & Adam (2011) and Hasnain *et al*., (2020) reported an increase in total dry mass by applying 100 ppm NAA and their findings are in line with those of ours.

Table 8. Economic analysis and BCR Ratio in transplanted coarse rice as affected by plant growth regulator levels at different growth stages during 2016 and 2017.

Plant growth stages + Plant growth regulator levels	2016						2017					
	Paddy yield t ha^{-1}	Total variable cost Rs. ha^{-1}	Gross income Rs. ha^{-1}	Total cost Rs. ha^{-1}	Net income Rs.ha^{-1}	BCR	Paddy yield t ha^{-1}	Total variable cost Rs. ha^{-1}	Gross income Rs.ha^{-1}	Total cost Rs. ha^{-1}	Net income Rs.ha^{-1}	BCR
S_1 (Tillering stage)	5.93	0	207550	90500	117050	1.29 AB	6.2	0	217000	90500	126500	1.39 B
S_2 (Panicle initiation stage)	6.65	0	232750	90500	142250	1.57 A	6.92	0	242200	90500	151700	1.67 A
S_3 (Grain formation stage)	5.33	0	186550	90500	96050	1.06 B	5.55	0	194250	90500	103750	1.14 C
G_0 (0ml ha^{-1})	5.17	0	182950	90500	90450	0.99 C	5.37	0	187950	90500	97450	1.07 C
G_1 (60ml ha^{-1})	6.17	45	215950	90545	125405	1.38 B	6.33	45	221550	90545	131005	1.44 B
G_2 (90ml ha^{-1})	7.11	60	248850	90560	158290	1.74 A	7.4	60	259000	90560	168440	1.85 A
G_3 (120ml ha^{-1})	5.48	75	191800	90575	101225	1.11 C	5.8	75	203000	90575	112425	1.24 C
S_1X G_0	5.2	0	182000	90500	91500	1.01 EF	5.4	0	189000	90500	98500	1.08 EF
S_1X G_1	6	45	210000	90545	119455	1.31 CD	6.2	45	217000	90545	126455	1.39 CD
S_1X G_2	7.15	60	250250	90560	159690	1.76 B	7.4	60	259000	90560	168440	1.85 B
S_1X G_3	5.5	75	192500	90575	101925	1.12 DE	5.8	75	203000	90575	112425	1.24 DE
S_2X G_0	5.3	0	185500	90500	95000	1.04 E	5.5	0	192500	90500	102000	1.12 DEF
S_2X G_1	7	45	245000	90545	154455	1.7 B	7.4	45	259000	90545	168455	1.86 B
S_2X G_2	8	60	280000	90560	189440	2.09 A	8.2	60	287000	90560	196440	2.16 A
S_2X G_3	6.3	75	220500	90575	129925	1.43 C	6.6	75	231000	90575	140425	1.55 C
S_3X G_0	5	0	175000	90500	84500	0.93 EF	5.2	0	182000	90500	91500	1.01 EF
S_3X G_1	5.5	45	192500	90545	101955	1.12 DE	5.4	45	189000	90545	98455	1.08 EF
S_3X G_2	6.2	60	217000	90560	126440	1.39 C	6.6	60	231000	90560	140440	1.55 C
S_3X G_3	4.62	75	161700	90575	71125	0.78 F	5	75	175000	90575	84425	0.93 F

Different letter(s) assigned to the mean values in a column show significance at 1% probability level

$LSD_{0.01}$ = 0.35 (Growth stages); $LSD_{0.01}$ = 0.39 (Growth stages); $LSD_{0.01}$ = 0.35 (Plant growth regulator); $LSD_{0.01}$ =0.44 (Plant growth regulator); $LSD_{0.01}$ = 0.61 (Interaction); $LSD_{0.01}$ =0.76 (Interaction)

The data in Table 2 exhibited almost a similar trend regarding straw yield (t ha^{-1}). The highest straw yield in interaction treatment of NAA @90 ml ha^{-1} applied at the panicle initiating stage might have been the result of active growth of leaves, stem and other vegetative parts of rice due to the action of NAA which caused extra growth and development compared with the other interaction combinations. These outcomes are similar to those reported by Alam *et al*., (2002) that NAA @ 20 ppm increased the straw yield of wheat.

The paddy yield is the end-product of tillers per unit area, grains per spike, 1000-grain weight and grain filling percentage. The increase of 42% in paddy yield by foliar spraying of NAA @ 90 ml ha^{-1} at the panicle initiation stage of coarse transplanted rice over the lowest yield by the interaction treatment NAA @ 120 ml ha^{-1} applied at the grain filling stage might have been due to overall growth promoting effect of NAA during the vegetative growth period of rice plants due to rapid cell elongation and multiplication in all vegetative stages. Liu *et al*., (2012) recorded an increase in paddy yield with 1000 mg L^{-1} of the plant growth regulator (gibberellic acid and α-naphthalene acetic acid). Choi *et al*., (2010) reported an increase in paddy yield by 26% over control with the use of a plant growth regulator (ICA). Similarly, Gurmani *et al*., (2006) revealed that grain yield of rice could be increased by using plant growth regulators such as ABA, BA and CCC. Similar to our findings, Hasnain *et al*., (2020) also showed enhanced yield with NAA@ 90 ml ha^{-1} in paddy crop. These plant growth regulators (PGRs) in general, help increase the number of flowers on the plant when applied at the time of flowering while flower and pod drop may be reduced to some extent by spraying various growth regulators on foliage (Ramesh & Thirumuguran, 2001).

There are genetic, physiological, and environmental limitations on rice production. HI is the partitioning of total dry matter into vegetative (leaves and culms) and reproductive parts (grains). The higher HI (42.32%) in the interaction with NAA @ 90 ml ha^{-1} applied at the panicle initiation stage (G2 x S2) compared to (35.53%) in G3 x S3 might have been due to higher total dry matter (TDM) that caused more translocation of carbohydrates into panicles. This treatment (G2 x S2) might also have initiated earlier flowering in that environment which allowed grain filling to occur before both temperature and the vapor pressure deficit increase. Armen *et al*., (2007), also working in the Mediterranean environment, found that higher yield in modern wheat cultivars in comparison with old cultivars was associated with earlier flowering.

Naphthalene acetic acid, being a synthetic counterpart of auxin, mediates cell division and expansion. It increases leaf emergence and expansion when applied in optimum quantities and at appropriate growth stage(s) (Muthukumar *et al*., 2007). Therefore, in the present study, higher leaf area index with NAA @ 90 ml ha^{-1} applied at the panicle initiation stage might have been due to the fact that this treatment gave more leaf expansion and elongation, thereby increasing LAI. Pal *et al*., (2009) applied varying concentration of a plant growth regulator (Triacontanol) on rice cropand found significantly different results for leaf area index. Their results are in line with the results of the present study.

During the initial growth stages, plants make efficient use of the inputs, i.e. water and nutrients and thus produce more assimilates than at the later stages of growth. At the later part of plant's life, assimilates are translocated from the source to the sink for better grain formation. This might be the reason for better crop growth rate at the tillering stage than the later growth stages. Similarly, antagonism between auxins and cytokinins could be also one of the reasons. Auxins in plants are active during the initial stages and suppress the activity of cytokinins causing more vegetative growth, whereas, during the later stages, reproductive growth may be promoted. Yokoya *et al*., (2013) noticed that indole acetic acid at lower concentration increased the crop growth rate and their results are in agreement with our results.

During the early growth period, the larger leaf area index (LAI), proper water and nutrient availability with ample supply of solar radiation may result in better photosynthetic efficiency compared to that at the reproductive stages. The treatments with NAA application enlarged the LAI during the vegetative period which created elevated photosynthetic efficiency than that in the untreated control (G0). The results of Baranyiova *et al*., (2014) did not agree with our findings who found that the photosynthetic efficiency of the crop was non-significantly altered when different concentrations of plant growth regulators were applied on it.

Being a ratio between gross income and cost of production, the highest BCR might have been due to highest paddy yield per unit area with almost comparable (not much different) variable cost, indicating highest net return for NAA @ 90 ml ha^{-1} applied at the panicle initiation stage treatment.

Reddy *et al*., (2009) reported highest BCR of 1.83 against NAA @ 100 g ha^{-1} with the highest net return. The NAA dose @ 90 ml ha^{-1} indicated in the experiment of Hasnain *et al*., (2020) was found very effective in improving grain yield of rice and hence resulting in better BCR values than that in the other treatments.

Conclusion

From the present study, it is concluded that different doses of NAA applied at different growth stages affected the overall grain yield differently of the transplanted coarse rice. The NAA level of 90 ml ha^{-1} applied at the panicle initiation and tillering stage substantially increased paddy yield, BCR and net return of transplanted coarse rice. It is, therefore concluded that application of plant growth regulator (NAA) @ 90 ml ha^{-1} at the panicle initiation and tillering stages could be a best choice for farming communities to obtain higher yield of transplanted paddy and net return.

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