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Enhancing Transplant *Aman* Rice Productivity through NPK Fertilizer Split Application Scheduling Under Zero Till Non-Puddled Condition

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ABSTRACT

This experiment was conducted at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh to evaluate the varietal response of split application of NPK fertilizer application schedule on transplant *aman* rice under zero till non-puddled condition. The experiment comprised three rice varieties *viz*. Bashiraj (local), BRRI dhan49 (inbred), Dhanigold (hybrid); and seven NPK fertilizer application schedules. The experiment was laid out in a randomized complete block design with three replications. The effect of variety, NPK fertilizer split application schedule and their interaction showed significant variation on the yield attributes and yield of *aman* rice. In interaction, the highest number of effective tillers hill^{-1} (11.66), total spikelets panicle^{-1} (164.00), grains panicle^{-1} (151.22), 1000-grain weight (38.70 g), grain yield (5.67 t ha^{-1}) and harvest index (60.36%) were obtained from hybrid variety Dhanigold when fertilized following 3-splits of N [1/3 at 14 days after transplanting (DAT) + 1/3 at maximum tillering (MT)+ 1/3 at panicle initiation (PI)] and P (1/3 as basal + 1/3 at MT + 1/3 at PI), and single split of K as basal (full dose). Same treatment combination also provides the highest yield of BRRI dhan49, but the local Bashiraj gave the highest yield at recommended practice where only N was top-dressed at 3 splits. Based on this result, it may be concluded that for better productivity hybrid Dhanigold and inbred BRRI dhan49 might be fertilized with 3-splits of N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) and P (1/3 as basal + 1/3 at MT + 1/3 at PI) and full dose of K as basal during *aman* season under zero till non-puddled condition. On the other hand, for local variety Bashiraj 3-spilts of N either [½ as basal + ¼ at active tillering (AT) + ¼ at PI] or N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) and P, K as single split (full dose) as basal appeared as the best application schedule.

1. Introduction

Rice (*Oryza sativa* L.) is a staple crop for approximately half of the world's population; its production should be significantly increased to fulfill the demands of an expanding global population (Khush, 2005). In Bangladesh, rice is the most extensively cultivated cereal crop and therefore, rice security of the country is sometimes considered as food security. About 78% of the net cropped areas of Bangladesh is used for rice production with an annual production of 36.6 million metric tons from an area of 11.45 million ha (BBS, 2020). Rice is cultivated in three seasons in the country namely, *aus, aman* and *boro*. The contribution of *boro* rice to national rice production is increasing at a rate of 0.97% per year, while *aus* and *aman* season production contributions significantly decreased by 0.48% and 0.49% per year, respectively (Rahman et al., 2021). Globally 503.17 MT rice is produced where China produces 29.5% of the total, followed by India (23.8%), Bangladesh (7.0%), Indonesia (6.9%), Vietnam (5.4%), and Thailand (3.7%) (Al Mamun et al. 2021; USDA 2021). Although, Bangladesh ranks 3rd position, with the ever-increasing demand for food security and sustainable agricultural practices, optimizing rice production has become imperative. Rice production can be increased by using improved varieties, judicious fertilizer uses and irrigation with proper management practices (Gairhe et al., 2018).

Puddled transplanting has been a widely adopted practice in the Asian countries, wherein fields are flooded before transplanting rice seedlings (Islam et al., 2023). However, this conventional method consumes huge amount of water and energy that required for puddling, leads to the

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depletion of vital nutrients, affecting overall soil health and increases the production cost (Chaki et al., 2021; Islam et al. 2023). In contrast, zero till non-puddled transplanting system is a conservation practice, offers water savings and improved soil health, and at the same time potentially increases profit and energy efficiency without any yield penalty (Islam et al., 2019; Gathala et al., 2020; Chaki et al., 2021).

The rate and application schedule of essential nutrients, such as nitrogen (N), phosphorus (P) and potassium (K) play a vital role in enhancing rice productivity. The recommended nutrient management practices such as application of full P and K and 50% N at the time of transplanting (basal) and the remaining N in two equal splits at active tillering and panicle initiation (top dressing) stages may not optimize nutrient utilization. Many researchers reported that post panicle initiation nutrient management may increase crop yield *e.g.,* application of N and K at the anthesis period enhanced the yield attributes and grain yield of hybrid rice (Nahar et al., 2023; Kumar et al., 2024). Potassium is a vital nutrient that regulates several physiological processes of crop plants. The K requirement is very high in hybrid rice than inbred and application of K at grain filling stage may promote rice yield than application at basal. It is well known that nutrient uptakes may be influenced by the cultivars and soil properties. Synchronized nutrient release enhances rice yield, particularly when timed with critical growth phases (Singh et al., 2018). For a particular location and cultivar, it has to be fixed by experimentation.

To the best of our knowledge, a very few research work related to split application of primary crop nutrient *e.g.,* N, P, K have been conducted on rice (Tiwari et al., 2015; 2016), and most of them were in upland crops *e.g.,* muskmelon (Aluko et al., 2021), cotton (Islam et al., 2013), maize (Fabunmi, 2009), garlic (Olfati et al., 2014), amaranthus (Alonge et al., 2007), groundnut (Chitdeshwari et al., 2007), quinoa (Ibrahim et al. 2020), etc. But research related to their split application in rice field is very scant. In this backdrop the current research was conducted to evaluate the performance of N, P and K split application schedule on the yield contributing characters and yield of the transplant *aman* rice under zero till non-puddled conditions, and to assess the interaction, if any, between variety and split application of N, P and K fertilizers schedule on the yield contributing characters and yield of transplant *aman* rice.

2. Materials and Methods

2.1. Description of the experimental site

The study was conducted at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh. It is located at 24°43'12.1" N latitude and 90°25'37.0"E longitude having an altitude of 18 m. The experimental site belongs to the *Sonatala* series of Old Brahmaputra Floodplain (AEZ-9) having non-calcareous dark-grey floodplain soils (UNDP and FAO, 1988). The land was medium high with moderate drainage facilities. The soil pH, bulk density, % Organic carbon, % total N, available P and K, electrical conductivity, C:N ratio and other properties of the experimental field were given in Table 1.

The climate of the experimental site was sub-tropical. It was characterized by its heavy rainfall during *kharif* season (April to September) and scanty rainfall occurred during Rabi season (October to March).

Table 1. Analyzed soil properties of the experimental field

Properties	Values
pH	7.20
Electrical conductivity EC (dS m^{-1})	0.045
Bulk density (g cm^{-3})	1.34
Organic carbon (%)	1.38
Total N (%)	0.15
C: N ratio	9.2
Phosphorus (ppm)	15.2
Potassium (meq 100 g^{-1})	0.065
Particle sizes	%
Sand	36
Silt	54
Clay	10
Texture	Silt loam

2.2. Planting material

Three rice varieties *viz*. *Bashiraj* (local), BRRI dhan49 (High yielding inbred) and Dhanigold (Hybrid) were used for the present experiment as test crops. The grain of the *Bashiraj* is light red in color and it requires about 135-145 days to mature, and gives a grain yield up to 3.5 t ha^{-1}. BRRI dhan49, an aman rice variety, was developed by the Bangladesh Rice Research Institute (BRRI). It is medium slender and fine rice. The variety is resistant to water logging. It attains a plant height of 100 cm and requires about 135 days to complete its life cycle. The variety gives a grain yield up to 5.5 t ha^{-1}. Dhanigold, a commercial hybrid rice variety marketed by ACI Seed. The variety has yield potential of 6-7 t ha^{-1} and complete its life cycle within 120-125 days. The variety is also resistant to BLB, blast disease and early shattering.

2.3. Experimental treatments and design

The experiment comprised three rice varieties *viz*. *Bashiraj* (local) (V_1), BRRI dhan49 (high yielder inbred) (V_2) and Dhanigold (hybrid) (V_3); and seven NPK fertilizer split application schedule *viz*. N [(1/3 at 14 days after transplanting (DAT) + 1/3 at maximum tillering (MT) + 1/3 at panicle initiation (PI)] + P (full dose as basal) + K (full dose as basal) (**T_1**), N (½ as basal + ¼ at AT (Active tillering) + ¼ at PI)+ P (full dose as basal) + K (full dose as basal) (**T_2**), N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal) + K (full dose as basal) (**T_3**), N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI) + K (full dose as basal) (**T_4**), N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal)+ K (1/3 as basal + 1/3 K at MT + 1/3 K at PI) (**T_5**), N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI)+ K (1/3 as basal + 1/3 at MT + 1/3 at PI) (**T_6**), N (½ as basal + ¼ at AT + ¼ at PI) + P (½ as basal + ¼ at AT + ¼ at PI) + K (½ as basal + ¼ at AT + ¼ at PI) (**T_7**). The experiment was laid out in a randomized complete block design (RCBD) with three replications. Therefore, the total number of plots was 63 = (7×3×3). The size of unit plot was 4 m × 2.5 m (10m²) and plot-to-plot distance was 1.0 m.

2.4. Crop husbandry

Pre-planting non-selective herbicide Roundup® (glyphosate 41% SL-IPA salt) was administered at a rate of 75 mL 10 L^{-1} water (2.25 L ha^{-1}) two weeks prior to the transplanting of ZT NPT field. The land was submerged in standing water for 48 hours, at a depth of 3-5 cm, prior to transplanting. Thirty-five days old seedlings were transplanted on 04 August maintaining row to row distance of 25 cm and hill to hill distance of 15 cm with 3 seedlings $hill^{-1}$. The experimental field was fertilized with 120, 20, 80, 16 and 2.1 kg ha^{-1} of N, P, K, S and Zn in the form of urea, triple super phosphate (TSP), muriate of potash (MoP), Gypsum and Zinc sulphate. The urea, TSP, MoP was applied as per treatment specification (either basal or top dressed), while gypsum and zinc sulphate were applied as basal. Two weeding with rice weeder were practiced to keep the land weed free. Since there was no noteworthy insect or disease infestation during the experimentation, no crop protection measures were administered to keep insects and diseases under control. Irrigation was provided when necessary.

2.5. Data recorded

The crop was harvested at maturity (when 90% of the seeds became golden yellow in color) from the central 2.0 m × 1.0 m of each plot to record data on grain and straw yield. Dhanigold, BRRI dhan49 and Bashiraj were harvested on 7, 21 and 30 November, respectively. Five hills were randomly collected from each plot to record data on yield contributing characters. The harvested crop of each plot was separately bundled, properly tagged, threshed and dried to 14% moisture level. Straws were sun dried properly. Final grain and straw yields $plot^{-1}$ were recorded and expressed in t ha^{-1}.

2.6. Statistical Analysis

Data recorded for yield contributing characters and yield were compiled and tabulated in proper form for statistical analyses. Analysis of variance was done with the help of Statistix 10 computer package program. The mean differences among the treatments were evaluated with Tukey's test (Gomez and Gomez, 1984).

3. Results

At harvest all the yield attributes and yield were significantly influenced by variety, NPK fertilizer split application schedule and their interaction except the effect of variety on number of effective and non-effective tillers $hill^{-1}$, and NPK fertilizer split application schedule on non-effective tillers $hill^{-1}$ and sterile spikelets $panicle^{-1}$ (Table 2 – 4).

3.1. Number of effective tillers $hill^{-1}$

The highest number of effective tillers $hill^{-1}$ (10.33) was obtained from the treatment T_2 – N (½ as basal + ¼ at AT (Active tillering) + ¼ at PI) + P (full dose as basal) + K (full dose as basal) and the lowest one (9.00) was obtained from T_1- N [1/3 at 14 DAT + 1/3 at maximum tillering (MT) + 1/3 at panicle initiation (PI)] + P (full dose as basal) + K (full dose as basal) (Table 3). In interaction, the highest number of effective tillers $hill^{-1}$ (11.66) was obtained from Dhanigold when fertilizer application splited at a sequence of N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI) + K (full dose as basal) (V_3T_4) and the lowest number of effective tillers $hill^{-1}$ (8.66) was found form Bashiraj applied with N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal) + K (full dose as basal) (V_1T_3) which was statistically similar to BRRI dhan49 with N [1/3 at 14 DAT + 1/3 at MT + 1/3 at PI] + P (full dose as basal) + K (full dose as basal) (V_3T_1) (Table 4).

3.2. Number of non- effective tillers $hill^{-1}$

The highest number of non-effective tillers $hill^{-1}$ (2.00) was obtained in T_1– N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (full as basal) + K (full as basal), while the lowest number of non-effective tillers $hill^{-1}$ (1.33) was obtained in T_2 – N (½ as basal + ¼ at AT + ¼ at PI)+ P (full as basal) + K (full as basal) which was statistically similar to T_4 - N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI) + K (full as basal) treatment (Table 3). In interaction, the highest number of non-effective tillers $hill^{-1}$ (2.33) was obtained from Bashiraj with N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI) + K (full dose as basal) (V_1T_4) and the same variety with N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal)+ K (1/3 as basal + 1/3 K at MT + 1/3 K at PI) (V_1T_5), while the lowest number one (0.66) was found form BRRI dhan49 when fertilized at the sequence of N (½ as basal + ¼ at AT + ¼ at PI)+ P (full dose as basal) + K (full dose as basal) (V_2T_2) (Table 4).

3.3. Panicle length

The highest panicle length (24.90 cm) was found in Dhanigold (V_3) and the lowest panicle length (23.42 cm) was found in BRRI dhan49 (V_2) which was statistically similar to local variety Bashiraj (V_1) (23.52 cm) (Table 2). In case of nutrient management practices, the longest panicle (24.44 cm) was found in T_3 - N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal) + K (full dose as basal) and shortest panicle length (23.55 cm) was found in T_5- N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (full as basal) + K (1/3 as basal + 1/3 K at MT + 1/3 K at PI) (Table 3). Panicle length was increased with the increased of split application of N, P and K.

In interaction between variety and NPK fertilizer split application schedule, the highest panicle length (25.66 cm) was obtained from Dhanigold with N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P (full as basal) + K (full as basal) (V_3T_3) and the lowest one (22.66 cm) was obtained from Bashiraj applied with N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal) + K (full dose as basal) (V_1T_1) which was statistically similar to (23.00 cm) the same variety when the fertilizer splited at N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal) + K (1/3 as basal + 1/3 K at MT + 1/3 K at PI) (V_1T_5) (Table 4).

Table 2. Effect of variety on yield contributing characters and yield of T. aman rice

Varieties (V)	Effective tillers hill^{-1} (no.)	Non-effective tillers hill^{-1} (no.)	Grains panicle^{-1} (no.)	Sterile spikelets panicle^{-1} (no.)	Panicle length (cm)	1000-grain weight (g)	Straw yield (t ha^{-1})	Harvest index (%)
Bashiraj	9.66	1.71	110.71^{c}	5.76^{c}	23.52^{b}	22.86^{c}	5.13^{a}	37.91^{c}
BRRI dhan49	9.47	1.52	121.48^{b}	9.81^{b}	23.42^{b}	34.49^{b}	4.48^{b}	43.62^{b}
Dhanigold	10.00	1.66	138.52^{a}	13.05^{a}	24.90^{a}	35.40^{a}	3.86^{c}	55.43^{a}
LS	NS	NS	***	***	***	***	***	***
$LSD_{0.05}$	0.60	0.47	2.92	1.63	0.46	0.56	0.40	2.88

In column, means followed by same letters are not significantly different. In column, means followed by different letters are significantly different where, *= Significant at 5% level of probability, ***= Significant at 0.1% level of probability, CV=Co-efficient of variance and NS=Not significance.

Table 3. Effect of split application schedule of NPK fertilizer on yield contributing characters and yield of T. aman rice

NPK fertilizer application schedule (T)	Effective tillers hill^{-1} (no.)	Non-effective tillers hill^{-1} (no.)	Grains panicle^{-1} (no.)	No. of sterile spikelets panicle^{-1}	Panicle length (cm)	1000-grain weight (g)	Straw yield (t ha^{-1})	Harvest index (%)
T_1	9.00^{c}	2.00	127.9^{b}	10.11a	24.11^{ab}	29.72^{c}	4.82^{a}	42.81^{b}
T_2	10.33^{a}	1.33	121.6^{cd}	9.1	24.00^{ab}	30.55^{bc}	4.51^{ab}	47.21^{a}
T_3	9.77^{abc}	1.66	134.6^{a}	9.56	24.44^{a}	31.22^{b}	4.08^{b}	48.73^{a}
T_4	10.22^{ab}	1.33	118.9^{d}	9.4	23.77^{ab}	30.79^{b}	4.33^{ab}	48.09^{a}
T_5	9.77^{abc}	1.66	125.7^{bc}	9.89	23.56^{b}	30.76^{b}	4.49^{ab}	44.90^{ab}
T_6	9.33^{bc}	1.66	125.9^{bc}	8.89	24.00^{ab}	32.13^{a}	4.61^{ab}	45.07^{ab}
T_7	9.55^{abc}	1.44	110.6^{e}	9.78	23.77^{ab}	31.23^{b}	4.59^{ab}	42.73^{b}
LS	*	NS	***	NS	*	***	*	*
$LSD_{0.05}$	0.92	0.72	4.47	2.49	0.71	0.86	0.62	4.40

In column, means followed by same letters are not significantly different. In column, means followed by different letters are significantly different where, *= Significant at 5% level of probability, *** = Significant at 0.1% level of probability, NS = Not significance. **T_1** = N [(1/3 at 14 days after transplanting (DAT) + 1/3 at maximum tillering (MT) + 1/3 at panicle initiation (PI)] + P (full dose as basal) + K (full dose as basal), **T_2**= N (½ as basal + ¼ at AT (Active tillering) + ¼ at PI)+ P (full dose as basal) + K (full as basal), **T_3** = N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal) + K (full dose as basal), **T_4** = N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI) + K (full dose as basal), **T_5** = N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal)+ K (1/3 as basal + 1/3 K at MT + 1/3 K at PI), **T_6** = N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI)+ K (1/3 as basal + 1/3 at MT + 1/3 at PI), **T_7** = N (½ as basal + ¼ at AT + ¼ at PI) + P (½ as basal + ¼ at AT + ¼ at PI) + K (½ as basal + ¼ at AT + ¼ at PI).

Table 4. Interaction effect of variety and NPK fertilizer split application schedule on yield contributing characters and yield of T. aman rice

V × T	Effective tillers hill^{-1} (no.)	Non-effective tillers hill^{-1} (no.)	Grains panicle^{-1} (no.)	Sterile spikelets panicle^{-1} (no.)	Panicle length (cm)	1000 - grain weight (g)	Straw yield (t ha^{-1})	Harvest index (%)
$V_1 \times T_1$	9.33^{cde}	1.00^{bc}	103.7^{h}	6.33^{fgh}	22.66^{g}	31.77^{f}	5.27^{ab}	37.99^{ij}
$V_1 \times T_2$	10.00^{b-e}	2.00^{ab}	108.3^{gh}	4.67^{gh}	23.66d^{-g}	35.52^{bc}	4.88^{a-d}	40.69^{g-j}
$V_1 \times T_3$	8.66^{e}	1.33^{abc}	123.7^{de}	7.33^{d-h}	24.33^{b-e}	35.46^{bc}	5.29^{ab}	38.62^{hij}
$V_1 \times T_4$	10.66^{abc}	2.33^{a}	94.3^{i}	7.67^{d-h}	23.33^{efg}	34.32^{cd}	5.03^{abc}	36.98^{ij}
$V_1 \times T_5$	9.66^{b-e}	2.33^{a}	113.3^{fg}	5.67^{fgh}	23.00^{fg}	35.37^{bc}	5.13^{abc}	37.38^{ij}
$V_1 \times T_6$	9.66^{b-e}	1.33^{abc}	107.0^{gh}	4.33^{h}	23.66^{d-g}	21.12^{j}	5.33^{ab}	36.96^{ij}
$V_1 \times T_7$	9.66^{b-e}	1.33^{abc}	124.7^{cde}	4.33^{h}	24.00^{c-f}	36.64^{b}	4.98^{a-d}	36.74^{ij}
$V_2 \times T_1$	9.00^{de}	2.00^{ab}	132.3^{bc}	12.67^{abc}	24.33^{b-e}	34.44^{cd}	4.86^{a-d}	41.22^{f-j}
$V_2 \times T_2$	9.33^{cde}	0.66^{c}	126.3^{cde}	10.67^{b-e}	24.00^{c-f}	32.66^{ef}	4.54^{a-f}	43.61^{e-i}
$V_2 \times T_3$	9.66^{b-e}	2.00^{ab}	128.7^{bcd}	9.33^{c-f}	23.33^{efg}	35.50^{bc}	3.47^{fg}	48.51^{c-f}
$V_2 \times T_4$	10.33^{a-d}	2.00^{ab}	105.0^{h}	7.00^{e-h}	23.00^{fg}	34.39^{cd}	4.29^{b-g}	46.94^{d-g}
$V_2 \times T_5$	10.00b^{-e}	1.00^{bc}	120.0^{ef}	9.00^{c-f}	23.00^{fg}	35.78^{bc}	4.08^{c-g}	45.63^{d-h}
$V_2 \times T_6$	9.00^{de}	2.00^{ab}	135.3^{b}	8.67^{c-g}	23.33^{efg}	33.34^{de}	4.59^{a-e}	43.47^{e-j}
$V_2 \times T_7$	9.00^{de}	1.00^{bc}	102.7^{h}	11.33^{a-d}	23.00^{fg}	35.32^{bc}	5.52^{a}	35.92^{j}
$V_3 \times T_1$	8.66^{e}	2.00^{ab}	147.7^{a}	11.33^{a-d}	25.33^{ab}	22.96^{ghi}	4.34^{b-f}	49.21^{cde}
$V_3 \times T_2$	9.66^{b-e}	1.66^{abc}	130.0^{bcd}	12.00^{abc}	24.33^{b-e}	23.47^{gh}	4.09^{c-g}	57.34^{ab}
$V_3 \times T_3$	11.00^{ab}	1.66^{abc}	132.3^{bc}	13.67^{ab}	25.66^{a}	22.71^{h}i	3.49^{fg}	59.07^{ab}
$V_3 \times T_4$	11.66^{a}	1.33^{abc}	151.3^{a}	12.00^{abc}	25.00^{abc}	38.70^{a}	3.67^{efg}	60.36^{a}
$V_3 \times T_5$	9.66^{b-e}	1.66^{abc}	143.7^{a}	15.00^{a}	24.66^{a-d}	23.67^{gh}	4.26^{b-g}	51.68^{bcd}
$V_3 \times T_6$	9.33^{cde}	1.66^{abc}	135.3^{b}	13.67^{ab}	25.00^{abc}	24.34^{g}	3.92^{d-g}	54.77^{abc}
$V_3 \times T_7$	10.00^{b-e}	2.00^{ab}	129.3^{bcd}	13.67^{ab}	24.33^{b-e}	21.73^{ij}	3.26^{g}	55.55^{abc}
LS	*	*	***	*	*	***	**	*
$LSD_{0.05}$	1.60	1.24	7.75	4.32	1.23	1.49	1.08	7.62

In column, means followed by different letters are significantly different where, *means significant at 5% level of probability, and ***means significant at 0.1% level of probability. Here, V_1=Bashiraj, V_2 =BRRI dhan49, V_3=Dhanigold. **T_1** = N [(1/3 at 14 days after transplanting (DAT) + 1/3 at maximum tillering (MT) + 1/3 at panicle initiation (PI)] + P (full dose as basal) + K (full dose as basal), **T_2**= N (½ as basal + ¼ at AT (Active tillering) + ¼ at PI)+ P (full dose as basal) + K (full as basal), **T_3** = N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal) + K (full dose as basal), **T_4** = N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI) + K (full dose as basal), **T_5** = N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal)+ K (1/3 as basal + 1/3 K at MT + 1/3 K at PI), **T_6** = N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI)+ K (1/3 as basal + 1/3 at MT + 1/3 at PI), **T_7** = N (½ as basal + ¼ at AT + ¼ at PI) + P (½ as basal + ¼ at AT + ¼ at PI) + K (½ as basal + ¼ at AT + ¼ at PI).

3.4. Grains panicle^{-1}

The highest number of grains panicle^{-1} (138.52) was obtained from Dhanigold (V_3) and the lowest number of grains panicle^{-1} (110.71) was obtained from Bashiraj (V_1) (Table 2). The highest number of grains panicle^{-1} (134.56) was obtained from T_3 - N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal) + K (full dose as basal), while the lowest one (110.56) was obtained from T_7 - N (½ as basal + ¼ at AT + ¼ at PI) + P (½ as basal + ¼ at AT + ¼ at PI) + K (½ as basal + ¼ at AT + ¼ at PI) (Table 3).

In interaction, the highest number of grains panicle^{-1} (151.33) was obtained from Dhanigold with N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI) + K (full dose as basal) (V_3T_4) which was statistically similar with Dhanigold with N [(1/3 at 14 DAT + 1/3 at MT + 1/3 at PI] + P (full dose as basal) + K (full dose as basal) (V_3T_1) and Dhanigold with N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal) + K (1/3 as basal + 1/3 K at MT + 1/3 K at PI) (V_3T_5). The lowest number of grains panicle^{-1} (94.33) was obtained from Bashiraj with N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI) + K (full dose as basal) (V_1T_4) (Table 4).

3.5. Sterile spikelets panicle^{-1}

The highest number of sterile spikelets panicle^{-1} (13.05) was found in Dhanigold (V_3), and the lowest number of sterile spikelets panicle^{-1} (5.67) was found in Bashiraj (V_1) (Table 2). In interaction, the highest number of sterile spikelets panicle^{-1} (15.00) was observed in Dhanigold with N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal)+ K (1/3 as basal + 1/3 K at MT + 1/3 K at PI) (V_3T_5), while the lowest number of sterile spikelets panicle^{-1} (7.00) was observed in BRRI dhan49 with N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI) + K (full dose as basal) (V_2T_4) (Table 4).

3.6. Thousand grain weight

The maximum weight of 1000-grain (35.40) was found in Dhanigold (V_3) and the lowest one (22.86) from Bashiraj (V_1) (Table 2). The maximum weight of 1000-grain (32.13) was obtained from T_6 - N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI)+ K (1/3 as basal + 1/3 at MT + 1/3 at PI), and the minimum weight of 1000-grain (29.72) was obtained from T_1- N [(1/3 at 14 days after transplanting (DAT) + 1/3 at maximum tillering (MT) + 1/3 at panicle initiation (PI)] + P (full dose as basal) + K (full dose as basal) (Table 3).

In interaction the maximum weight of 1000-grain (38.70) was observed in Dhanigold with N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI) + K (full dose as basal) (V_3T_4), the minimum weight of 1000-grain (21.12) was observed in Bashiraj with N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI)+ K (1/3 as basal + 1/3 at MT + 1/3 at PI) (V_1T_6) (Table 4).

3.7. Grain yield

The highest grain yield (4.85 t ha^{-1}) was obtained from Dhanigold (V_3), while the lowest one (3.11 t ha^{-1}) was obtained from Bashiraj (V_1) (Figure 1). In case of nutrient management, the highest grain yield (4.14 t ha^{-1}) was obtained from T_4 - N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI) + K (full dose as basal). The lowest grain yield (3.35 t ha^{-1}) was obtained from T_7 - N (½ as basal + ¼ at AT + ¼ at PI) + P (½ as basal + ¼ at AT + ¼ at PI) + K (½ as basal + ¼ at AT + ¼ at PI) (Figure 2). In interaction, highest grain yield (5.67t ha^{-1}) was observed in Dhanigold with N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI) + K (full dose as basal) (V_3T_4), and the lowest grain yield (2.88 t ha^{-1}) was observed in Bashiraj with N (½ as basal + ¼ at AT + ¼ at PI) + P (½ as basal + ¼ at AT + ¼ at PI) + K (½ as basal + ¼ at AT + ¼ at PI) (V_1T_7) (Figure 3).

3.8. Straw yield

The highest straw yield (5.13 t ha^{-1}) was obtained from Bashiraj (V_1) and the lowest straw yield (3.86 t ha^{-1}) was obtained from Dhanigold (V_3) (Table 2). In case of nutrient management, the highest straw yield (4.82 t ha^{-1}) was obtained from T_1 - N [(1/3 at 14 days after transplanting (DAT) + 1/3 at maximum tillering (MT) + 1/3 at panicle initiation (PI)] + P (full dose as basal) + K (full dose as basal). The lowest straw yield (4.08 t ha^{-1}) was obtained from T_3 - N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal) + K (full dose as basal) (Table 3). In interaction, the highest straw yield (5.52 t ha^{-1}) was observed in BRRIdhan49 with N (½ as basal + ¼ at AT + ¼ at PI) + P (½ as basal + ¼ at AT + ¼ at PI) + K (½ as basal + ¼ at AT + ¼ at PI) (V_2T_7). Lowest straw yield (3.26 t ha^{-1}) was observed in Dhanigold with N (½ as basal + ¼ at AT + ¼ at PI) + P (½ as basal + ¼ at AT + ¼ at PI) + K (½ as basal + ¼ at AT + ¼ at PI) (V_3T_7) (Table 4).

3.9. Harvest index

The highest harvest index (55.43%) was obtained from Dhanigold (V_3) and the lowest harvest index (37.91%) was obtained from V_1 (Table 2). In case nutrient management, the highest harvest index (48.73%) was obtained from T_3- N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal) + K (full dose as basal), statistically similar with T_2 - N (½ as basal + ¼ at AT (Active tillering) + ¼ at PI)+ P (full dose as basal) + K (full dose as basal) and T_4- N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI) + K (full dose as basal). While, the lowest harvest index (42.73%) was obtained from T_7 – N (½ as basal + ¼ at AT + ¼ at PI) + P (½ as basal + ¼ at AT + ¼ at PI) + K (½ as basal + ¼ at AT + ¼ at PI) (Table 3). In case of interaction, the highest harvest index (60.36%) was observed in Dhanigold with N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI) + K (full dose as basal) (V_3T_4) and the lowest harvest index (35.92%) was observed in BRRIdhan49 with N (½ as basal + ¼ at AT + ¼ at PI) + P (½ as basal + ¼ at AT + ¼ at PI) + K (½ as basal + ¼ at AT + ¼ at PI) (V_2T_7) (Table 4).

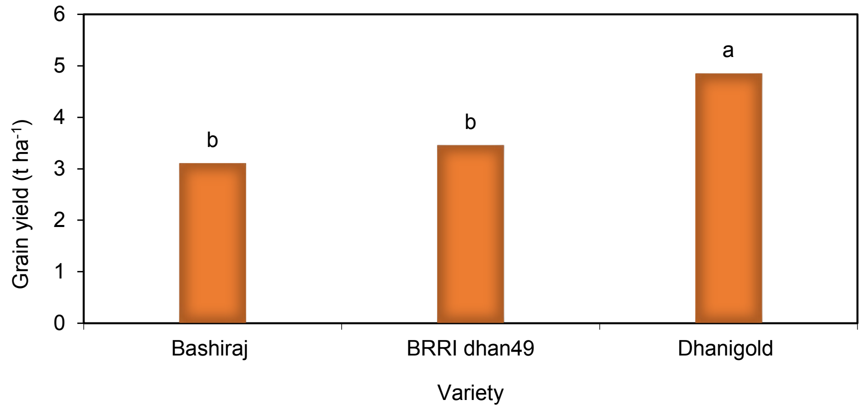

Figure 1. Effect of variety on grain yield of three T. aman rice varieties

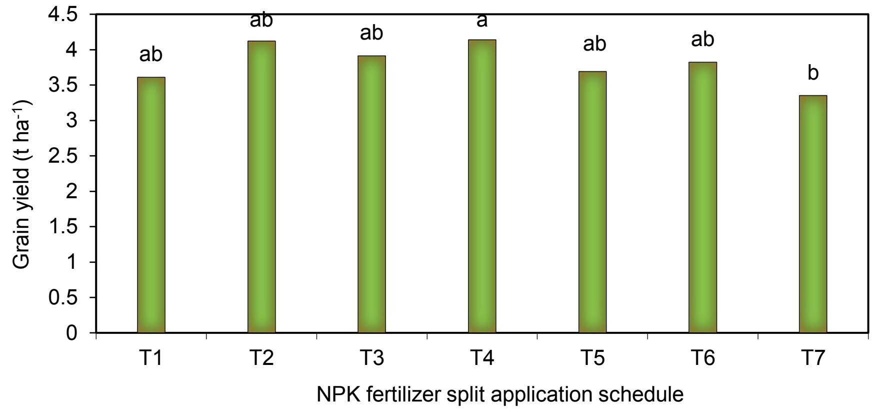

Figure 2. Effect of NPK fertilizer split application schedule on grain yield of three T. aman rice varieties

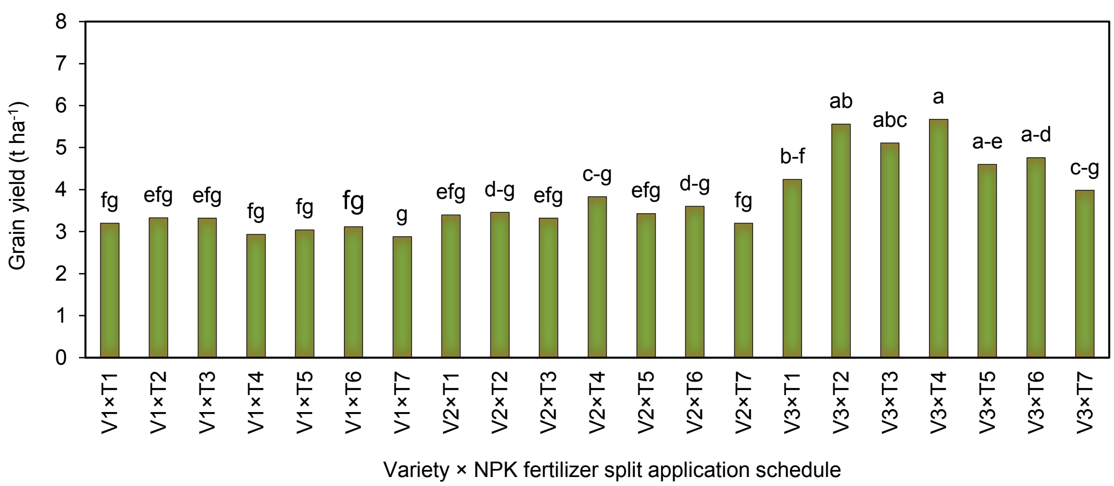

Figure 3. Interaction effect of variety and NPK fertilizer split application schedule on grain yield of three T. aman rice varieties

Here, V_1=Bashiraj, V_2 =BRRI dhan49, V_3=Dhanigold. $\mathbf{T_1}$ = N [(1/3 at 14 days after transplanting (DAT) + 1/3 at maximum tillering (MT) + 1/3 at panicle initiation (PI)] + P (full dose as basal) + K (full dose as basal), $\mathbf{T_2}$= N (½ as basal + ¼ at AT (Active tillering) + ¼ at PI)+ P (full dose as basal) + K (full as basal), $\mathbf{T_3}$ = N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal) + K (full dose as basal), $\mathbf{T_4}$ = N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI) + K (full dose as basal), $\mathbf{T_5}$ = N (1/3 at 14 DAT + 1/3 at MT + 1/3 at PI) + P (full dose as basal)+ K (1/3 as basal + 1/3 K at MT + 1/3 K at PI), $\mathbf{T_6}$ = N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P (1/3 as basal + 1/3 at MT + 1/3 at PI)+ K (1/3 as basal + 1/3 at MT + 1/3 at PI), $\mathbf{T_7}$ = N (½ as basal + ¼ at AT + ¼ at PI) + P (½ as basal + ¼ at AT + ¼ at PI) + K (½ as basal + ¼ at AT + ¼ at PI).

4. Discussion

Among the primary macro nutrients (N, P and K), nitrogenous fertilizers (highly mobile in soil) are generally applied as split to reduce their losses through leaching, volatilization, and runoff. This effective strategy of N fertilizers in rice cultivation may optimize nutrient use, minimize losses, and improve crop yield. Although P and K fertilizers are less mobile in the soil, splitting K applications ensures its availability during grain filling, leading to improved grain quality and weight. However, our research observed that hybrid aman variety Dhanigold gave highest grain yield when N and P-fertilizers were applied at 3-splits *i.e.* N [1/3 at 14 days after transplanting (DAT) + 1/3 at maximum tillering (MT)+ 1/3 at panicle initiation (PI)] and P (1/3 as basal + 1/3 at MT + 1/3 at PI), and single split of K as basal (full dose). Inbred aman variety BRRI dhan49 also gave the highest grain yield when NPK-fertilizers were applied at the same splits-sequence. However, the local aman variety Bashiraj gave the highest yield when those fertilizers were applied as a regular practice *i.e.* N at 3-splits (½ as basal + ¼ at active tillering + ¼ at panicle initiation) and P, K (full dose) were applied as basal. Kaushal et al. (2010) also observed highest grain yield when N was applied at 3-splits (½ as basal + ¼ at active tillering + ¼ at panicle initiation), while Kamruzzaman et al. (2013) also reported the same except the time of N application (⅓ N at 15 DAT + ⅓ N at 30 DAT + ⅓ N at 45 DAT).

Chen et al. (2015) demonstrated that split application of N fertilizer in rice led to higher nitrogen use efficiency compared to a single basal application, as the plant was able to absorb N at critical growth stages such as tillering and panicle initiation. Although a number of studies have been reported about the positive role of K split applications on the grain yield and quality (Manzoor et al., 2008; Seema and Jagdish, 2021; Vijayakumar et al., 2024), current study didn't get any yield advantage because of this split application.

On the other hand, a mark yield advantage was observed due to the split application of P – fertilizer. Split application of P, where the nutrient is applied at different growth stages, has shown promising results in terms of rice productivity. It helps in maintaining a consistent supply of P during crucial growth phases, leading to improved root growth, tillering, and grain filling (Savant and Stangel, 1990). A study by Rehim et al. (2012) demonstrated that split application of P enhanced rice yield compared to a single basal dose, as it minimizes P fixation in the soil and improves nutrient use efficiency.

As stated in the materials and methods that the experimental soil is almost neutral in reaction. The neutral soil conditions can sometimes result in the reduced availability of phosphorus due to fixation in soil particles. Split application of P can mitigate this issue by reducing the concentration of P in the soil at any given time, thereby enhancing the availability of the nutrient for plant uptake (Dobermann and Fairhurst, 2000). This approach ensures that the rice plants receive adequate P during key growth stages, resulting in improved physiological performance and higher grain yield (Saleque et al., 2000). On the other hand, P use efficiency is often low in rice due to losses through fixation and leaching. Split P application can improve nutrient use efficiency by synchronizing P availability with plant demand (Singh and Singh, 2002). By dividing the P doses, the risk of nutrient loss is minimized, leading to better utilization of applied P and subsequently higher yields.

Positive relationship of two splits of P application were reported by Rao et al. (1973), Ramaiah (1979), Budhar (1992). Similar positive results in three splits of P were reported by Singh et al. (1988) and Yadav et al. (2004) and four splits of P were reported by Thakur (1993). In addition, Archana et al. (2017) observed higher P uptake by the rice grain in split P application than the treatment receiving basal P, although split application had no significant influence on the increase in grain yield of rice. However, non-significant differences in grain yield due to split P application were also reported by Sahu and Sahoo (1969), Balasubramanian et al. (1982) and Reddy et al., (1984).

5. Conclusion

The experimental results revealed that split application of the primary nutrients significantly influenced the yield attributes and yield of local, inbred HYV and hybrid aman rice under zero till non-puddled condition. Based on the results obtained in this study, it may be concluded that for better productivity hybrid Dhanigold and inbred BRRI dhan49 might be fertilized following the schedule of N [1/3 at 14 days after transplanting (DAT) + 1/3 at maximum tillering (MT)+ 1/3 at panicle initiation (PI)] and P (1/3 as basal + 1/3 at MT + 1/3 at PI), and single split of K as basal (full dose) during *aman* season under zero till non-puddled condition. On the other hand, local variety Bashiraj might be fertilized following the schedule 3-splits of N [½ as basal + ¼ at active tillering (AT) + ¼ at PI] or N (1/3 at 7 DAT + 1/3 at MT + 1/3 at PI) + P and K (as full dose) as basal (during final land preparation) *i.e* the recommended practice. However, this experiment was conducted in a single location and single season, therefore multi location and multi season trials should have to be conducted for validation before final recommendation.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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