



RESEARCH ARTICLE

Optimizing potash management for enhanced productivity and profitability in black rice (*Oryza sativa*) cultivation under SRI system

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Abstract

An agronomic investigation was carried out at Instructional-cum-Research Farm of Assam Agricultural University, Jorhat, Assam, during kharif season of 2019–20 and 2020–21 to assess the effect of potash on growth, yield and quality parameters of black rice under organic ecosystem of Northeast India. The experiment was laid out in a randomized block design (RBD) with three replications and twelve different treatments. The experimental data recorded during both successive years revealed that the growth and physiological attributes of organic black rice was significantly influenced by different potassium management practices. Among the different growth and physiological parameters, such as numbers of leaves hill⁻¹, root length, root volume, chlorophyll content, stomatal index and phyllochron index were observed to be significantly higher with the application of recommended dose of fertilizer through banana pseudo stem vermicompost + mustard oil cake at 20 kg ha⁻¹ (T₈), which was statistically at par with T₆. The lowest values were recorded under the control treatment (T₁). Hence, it can be concluded that the integrated application of banana pseudostem vermicompost along with mustard oil cake at 20 kg ha⁻¹ proved to be the most effective potassium management strategy for enhancing the growth, physiological performance and overall productivity of organic black rice under the agro-climatic conditions of North East India.

Keywords: black rice; chlorophyll; morpho-phenology; potash; phyllochron index; stomatal index

Introduction

Oryza sativa as a staple food consumed by more than half of the World population to meet their dietary requirement. This crop is the backbone of livelihood for millions of rural households and plays vital role in the country's food security, so the term "rice is life" is most appropriate in Indian context. Over 90 % of the world's rice is produced and consumed in Asia, making it the second most significant cereal globally (1). Rice production contributes significantly as a source of livelihood for more than 50 million households across South Asian countries, namely China, India, Sri Lanka, Indonesia, Nepal, Bangladesh and others (2, 3).

However, in recent years, a particular type of pigmented rice called 'black rice' has come into the market as a more healthy and nutritious option claiming to be healthier than white rice. With the changing lifestyle and attitude towards healthy living and eating habits, consumers quickly switch towards healthier options such as black rice, brown rice, red rice, etc. Black rice, also known as forbidden rice, heaven rice, imperial rice, King's rice and prized rice, is aromatic and dark purple or black due to the presence of anthocyanins, which are powerful antioxidants (4–7).

Black rice can be considered the twenty-first century 'super food' (5). The consumption of black rice is said to be helpful in the prevention of heart disease, obesity, diabetes, cancer and aging (8–10). Black rice also contains superior essential amino acids than white rice and helps prevent diabetes and proper liver functioning (11, 12). The American Health Association and the American Cancer Society have also recommended its use (13).

Due to the presence of these medicinal properties, researchers are interested in studying black rice's nutritional and functional properties and its application in different technologies. About 200 different varieties of black rice exist in the world. China alone produces 62 % of the world's black rice and has created more than 54 modern black rice types with traits that increase yield. Most black rice is grown in China, followed by Sri Lanka, Indonesia, India, Philippines and others (5, 14, 15). Black rice was challenging to find before the modern era. For ages, it had been highly prized and guarded in Asia. Also, due to its nutritional and therapeutic value, this rice is steadily gaining popularity among dieticians and rice consumers. In the context of India, this new variety of rice is mainly cultivated in the Northeastern states such as Manipur, Assam and Meghalaya (7, 16–18).

Rice cultivation accounts for about 96 % of the state's entire food grain production and covers 64 % of the gross cropped area of the state (4). Since Assam is renowned for having a wide range of rice genetic variations, farmers have started cultivating black rice, which can be due to the increase in the health consciousness of the people and the demand for healthy and nutritious food products in the market. Black rice is grown in certain pockets of lower Assam and central Assam. The cultivation is relatively recent but has garnered attention at the national and international levels (19).

In the Goalpara district of lower Assam, black rice cultivation has recently started and over 200 farmers are opting to cultivate black rice over other rice varieties (4). Over the period, the number of black rice growers in the Goalpara district of Assam increased to around 900 in number in 2020 (19). Assam's black rice production and cultivation area have been increasing, as more farmers are drawn toward the cultivation of this crop. Looking at the success of this crop, the Government of Assam has proposed to promote the organic farming of specialized rice varieties like black rice and red rice, emphasizing domestic and foreign markets (4).

Potassium plays an important role in enzyme activation, photosynthesis, photosynthate translocation, protein synthesis and plant water relations and is also vital in the plant's ability to resist disease (20). Potassium is an essential nutrient for plant growth, but it generally receives less attention than N and P. All Indian soils utilized more K from the soil through crop harvests than are returned to the soil in terms of fertilizer and manure. This net export of soil nutrients ultimately results in a depletion of nutrients and increasing occurrences of deficiency.

Potassium is required in the greater amounts to plants, regardless of nutrient management philosophy. Some specific roles of K in the plant include osmo-regulation, internal cation/anion balance, enzyme activation and proper water relations. Potassium plays a vital role in photosynthate translocation, especially to grains, tubers and fruits. Protein synthesis is facilitated with an adequate supply of tolerance of external stress, such as frost, drought, heat and high light intensity is enhanced with proper K nutrition. Stresses from disease and insect damage are also reduced with an adequate supply of K. Although there are no harmful effects of K to the environment or to human health, the consequences of inadequate K may be related to poor crop health and inefficient utilization of other nutrients, such as N and P. Therefore, maintenance of adequate K is essential for both organic and conventional crop production (21).

Research on banana pseudo stem vermicompost suggests its application as a source of potassium. Vermicompost prepared from banana waste contains 5.6–6.2 % of potassium. The remarkably high K content in banana pseudo-stem would indicate its potentiality as organic K source. Moreover, to an agriculturist, turning agricultural waste into income generating products may be a pet dream (22).

The system of rice intensification (SRI) system is a method that employs the transplantation of one to two healthy and vigorous seedlings on a wider spacing with alternate drying and wetting periods of the field in practice (23). Transplanting rice on a wider spacing with square pattern has been found to have edge effect and help to produce more (24). Crop geometry affects yield by influencing the interception of solar radiation, crop canopy coverage and total dry matter accumulation (25). Closer planting

geometry increases competition among plants, which retards growth and yield-attributing parameters of crops (26). In contrast, wider spacing reduces the total tillers per cultivated area and thus reduces the grain yield of the crop (27).

Black rice is a tillering shy crop with low tillering ability and subsequent low productivity (25). However, the tillering ability isn't explored in the alternate transplanting method like SRI, where there are chances of increasing the tillering and yield potential of black rice. The yield attributing characters of rice were higher in plots under SRI method as compared to traditional method (1). They reported that the yield attributes such as plant height, effective tiller hill¹, panicle length, number of grain panicle¹ and test weight were found significantly higher in SRI method as compared to traditional method. Maximum pooled grain yield of rice was recorded in case of SRI as compared to traditional method (1).

Materials and Methods

Experimental site description

The experiment was conducted at certified organic block of the Instructional-Cum-Research (ICR) Farm of the Assam Agricultural University (AAU), Jorhat during kharif season of 2019–20 and 2020–21 under rainfed medium land situation. The farm is located at 26° 47'N latitude and 94° 12'E longitudes at an elevation of about 86.6 m above mean sea level. The topography of experimental field was uniform and levelled.

The representative soil samples from 0 to 30 cm depth were taken from randomly selected plots all over the experimental field before laying out the experiment. The soil of the experimental site was sandy loam in texture with pH 5.3, low in available nitrogen (246.45 kg ha⁻¹), phosphorus (21.02 kg ha⁻¹) and available potassium (144.80 kg ha⁻¹) and medium in organic carbon (0.72 %). The total rainfall received was 110.6 mm in 2019 and 1272.1 mm in 2020 during the cropping period (Fig. 1, 2). The cropping history of certified organic experimental plot for last three years is presented

Table 1. Cropping history of experimental field

Year	Kharif	Rabi	Summer
2016–17	Rice	Rice	Fallow
2017–18	Rice	Rice	Fallow
2018–19	Rice	Rice	Fallow
2019–20	Present investigation	Fallow	
2020–21	Present investigation	Fallow	

in Table 1.

Experimental details

The experiment consisted of twelve different treatments with alone and combination of organic nutrient sources such as control (T₁), potash solubilizing bacteria (KSB) at 3.5 kg ha⁻¹ as root dip treatment (T₂), recommended dose of potash (RDK) through *Azolla* incorporation (T₃), RDK through water hyacinth incorporation (T₄), RDK through banana pseudo stem vermicompost (T₅), RDK through *Azolla* incorporation + mustard oil cake at 20 kg ha⁻¹ (T₆), RDK through water hyacinth incorporation + mustard oil cake at 20 kg ha⁻¹ (T₇), RDK through banana pseudo stem vermicompost + mustard oil cake at 20 kg ha⁻¹ (T₈), RDK through *Azolla* incorporation + KSB at 3.5 kg ha⁻¹ as root dip treatment (T₉), RDK through water hyacinth incorporation + KSB at 3.5 kg ha⁻¹ (T₁₀), RDK through banana pseudo stem vermicompost + KSB at 3.5 kg ha⁻¹ (T₁₁),

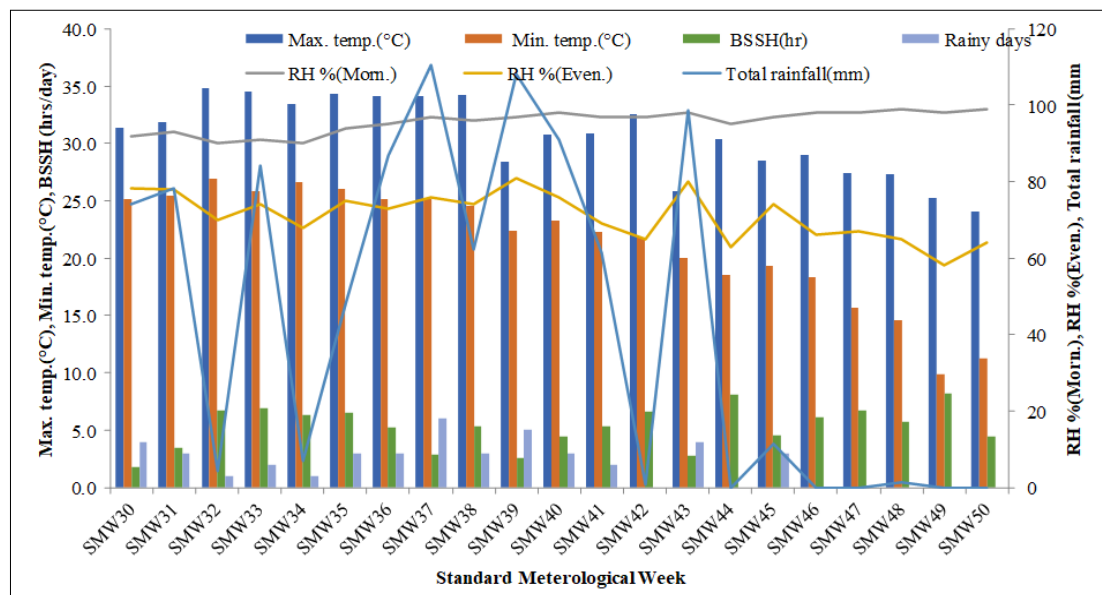


Fig. 1. Graphical representation of the weekly meteorological data observed during the crop growth period, 2019–20.

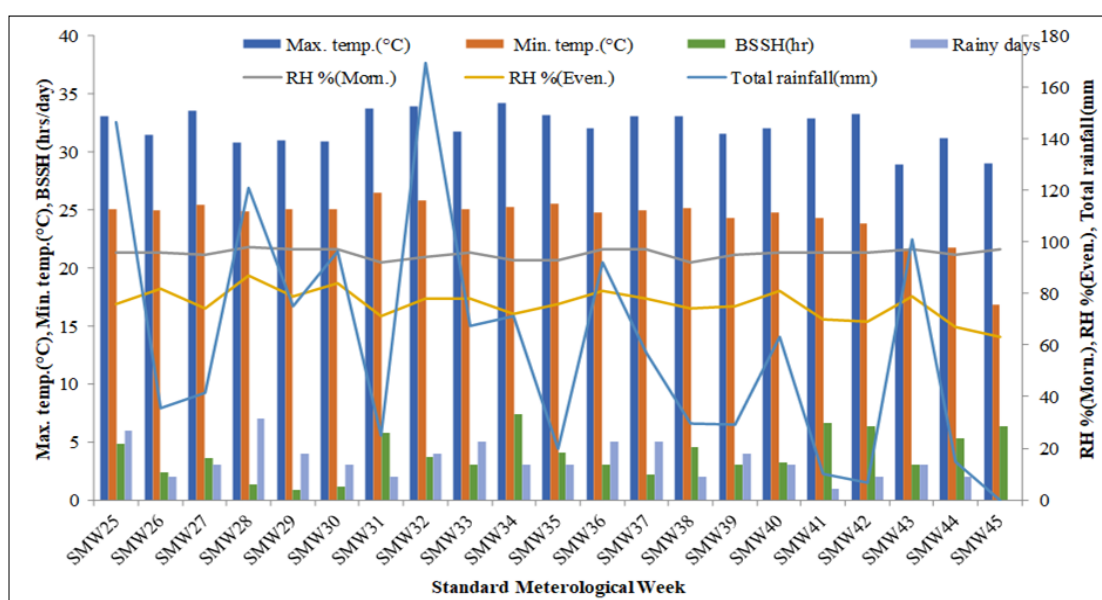


Fig. 2. Graphical representation of the weekly meteorological data observed during the crop growth period, 2020–21.

indigenous traditional knowledge (wood ash + fish washing water application) (T_{12}).

The experiment was laid out in a randomized block design (RBD) with three replications. The gross size of the area was 563.75 m² and net area was 432 m². The seeding was raised on nursery bed and after 14 days the seedlings were transplanted into main field by keeping 25 × 25 cm spacing between plant to plant and between row to row. The individual plot size was 4 m × 3 m. Sowing was done under system of rice intensification. The organic inputs were incorporated into each experimental plot before one month.

Climatic conditions of experimental field

The experimental site, Jorhat falls in the upper Brahmaputra valley agro-climatic zone of Assam. The zone is characterized by a sub-tropical climate with hot humid summer and relatively dry and cold winter. Falling in the south-west monsoon region, it receives total mean annual precipitation of about 2014 mm. Normally, monsoon rain starts from the month of June and continues up to the month of September and sometimes even up to first week of October with the pre-monsoon showers from mid-March to April. The intensity of rainfall decreases from mid of September reaching

minimum or zero during December–January.

The relative humidity of this zone is high (above 80 %) during the kharif season as the region is in sub-tropical humid region. The maximum temperature range is 34–37 °C during the summer and the minimum temperature range falls between 8–10 °C during the winter. In the first year of experimentation, the mean maximum bright sunshine hours (hr day⁻¹) were as high as 8.2 hr day⁻¹ in the 49 SMW (3 December to 9 December 2019). The lowest bright sunshine hr was recorded as 1.8 hr day⁻¹ in the 30 SMW (23 July to 29 July 2019). The corresponding values for the second year of experimentation were 7.4 hr day⁻¹ in the 34 SMW (20 August to 26 August 2020) and 0.9 hr day⁻¹ in the 29 SMW (16 July–22 July 2020) Fig. 1, 2.

Collection of experimental data

Five plants or hills were selected randomly from the net plot area of each plot as observational plants and these plants were tagged for periodical observations on growth and yield parameters.

Number of leaves hill⁻¹

Five hills were selected in each plot leaving the border rows of the

plot and the total number of tillers of individual hill was counted at 30 days interval. The average values were recorded and expressed in numbers hill⁻¹.

Leaf area index (LAI)

Leaf area index is defined as leaf area (assimilatory source) per unit land area. It was calculated at 30 days interval as per the formula given by Watson (1952).

Root length (cm)

Roots were dug out at different stages of growth according to the method of Sirohi et al. (1978). Soil was separated from roots by gentle washing. Roots were further washed over a fine sieve. The length of the root was measured in centimetre from root/shoot demarcation point to root tip with the help of thread and metallic measuring tape.

Root volume (Cubic centimetre)

Root volume was determined by water displacement method used by Raja and Bishnoi (1990) and was expressed as cubic centimetre (CC). After measuring the root length of 10 randomly selected seedlings or hills, the root of each treatment was submerged in 200–500 CC water taking in a 1000 CC measuring cylinder, the water raised in the cylinder was noted to measure root volume of the seedling and expressed as cc/hill.

Stomatal index

The percent of stomata of the total number of epidermal cells is called stomatal index. It is calculated by using following formula:

$$SI = \frac{S}{S+E} \times 100$$

Where, SI = stomatal index

S = number of stomata per unit area

E = number of other epidermal cells per unit area

Phyllochron index

Phyllochron is the time interval for appearance of successive leaf (Langer, 1972). The phyllochron of black rice plants was measured by counting the number of days taken for production of subsequent leaf from different branches of each plant and average values were recorded for each treatment.

Statistical analysis

The data collected from the current investigation were statistically analysed using Microsoft Excel and OPSTAT. A significance level of

$p = 0.05$ was utilized for both F and t tests. Critical differences were computed whenever the F tests yielded significant results. The RStudio software was used to depict a graphical representation of the data.

Results and Discussion

Number of leaves

It was evident that the number of leaves hill⁻¹ increased with the advancement in the age of the crop up to 120 days of transplanting (DAT) and thereafter decreased on account of senescence at harvest. It was further observed that, a greater number of functional leaves hill⁻¹ were recorded during the year 2020 than 2019. Result showed that higher number of functional leaves (174.66 and 181.66) were recorded under treatment (T₈) with application of RDK through banana pseudo stem compost along with mustard oil cake 20 kg ha⁻¹ followed by T₆ RDK through *Azolla* incorporation + Mustard oil cake at 20 kg ha⁻¹. The higher number of leaves hill⁻¹ under treatment T₈ might be due to favourable climatic conditions and balanced supply of nutrients through banana pseudo stem vermicompost along with mustard oil cake.

Leaf area index (LAI)

The data pertaining to LAI of black rice at different growth stages were significantly influenced by varied organic inputs and are presented in Table 2. The differences in LAI due to the incorporation of varied organic inputs in all observations were found significant during both the years of experimentation except at 30 DAT.

The treatment T₈ produced the highest leaf area index (LAI), however it was found to be statistically at par with the treatment T₆, T₇ and T₁₁. The LAI was steady up to 90 DAT and thereafter it declined irrespective of treatments due to senescence of older leaves as the crop progressed towards physiological maturity.

Root length

The data of the root length (cm) plant⁻¹ as influenced by different K management practices during both the years of the study (Table 2). Data revealed that, rate of increase in root length of rapidly up to 120 DAT and thereafter, the rate was slightly slowed down with the decreasing rate up to harvest. The treatment T₈ recorded highest root length (48.73 and 52.17) during 2019–2020. Significantly lower root length of black rice was recorded under the control (T₁) in both

Table 2. Root dry weight, shoot dry weight and root: shoot ratio of black rice as influenced by different organic treatments during 2019–2020 and 2020–2021 at 30, 60 and 90 DAT

Treatment	Numbers of leaves hill ⁻¹		Leaf area index		Root length (cm)	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
T ₁	149.09	156.09	4.12	4.18	29.00	28.40
T ₂	153.10	160.10	4.34	4.40	31.10	30.70
T ₃	159.58	166.58	4.45	4.54	36.33	35.17
T ₄	157.39	164.39	4.39	4.48	33.40	33.77
T ₅	162.48	169.48	4.56	4.64	37.67	37.03
T ₆	172.64	179.64	5.38	5.45	45.77	48.63
T ₇	170.24	177.24	5.24	5.30	43.90	46.57
T ₈	174.66	181.66	5.48	5.54	48.73	52.17
T ₉	167.45	174.45	5.04	5.10	40.73	40.57
T ₁₀	165.18	172.18	4.86	4.92	38.67	40.10
T ₁₁	168.89	175.89	5.16	5.22	41.50	42.93
T ₁₂	163.74	170.74	4.64	4.72	38.33	39.57
SEm±	5.18	5.22	0.30	0.31	2.45	2.50
CD (P = 0.05)	10.19	10.31	0.57	0.61	7.18	7.33

the years. The higher root length might be due to the applying RDK through banana pseudostem vermicompost and mustard oil cake enhances root development by providing essential nutrients, adding organic matter for improved soil structure and promoting microbial activity. Potassium supports root growth by regulating water uptake, while mustard oil cake acts as a biostimulant, encouraging deeper and stronger root systems.

Chlorophyll content

The various organic treatments recorded non-significant effect on chlorophyll (chlorophyll a, chlorophyll b and total chlorophyll) content in fresh leaf at PI and flowering stage (Table 3). Chlorophyll a was found to be higher than chlorophyll b irrespective of treatments, indicating proper growth of the crop without light stress. The total chlorophyll content also indicated the normal crop growth without shading effect. However highest values in respect of chlorophyll a, chlorophyll b and total chlorophyll were reported with T₈ treatment, followed by T₆ treatment during both the 2019 and 2020.

Root volume

Data revealed that, rate of increase in root volume (cm³ plant⁻¹) was increased rapidly up to 120 DAT and thereafter, rate was slightly slowed down with the decreasing rate up to physiological maturity. The application of RDK through banana pseudo stem vermicompost + mustard oil cake at 20 kg ha⁻¹ treatment (T₈)

observed significantly superior with respect to highest root volume, which was found to be statistically at par with T₆ treatment at 30 DAT and 120 DAT over all treatments (Fig. 3, 4). Significantly lowest root volume was recorded in treatment T₁ (Control). The highest root volume under treatment T₈ might be due to more favourable plant root environment due to adaptation of system of rice intensification with addition of nutrient through banana pseudo stem vermicompost which is a powerhouse of many essential plant nutrient and growth promoting enzymes.

Stomatal index

The stomatal index relates the number of stomata per unit of leaf area to the number of epidermal cells in the same leaf area. The data with respect to stomatal index were favourably influenced by different K management practices at PI stage during 2019 and 2020 are presented in Fig. 5. Hence, it is found that the maximum number of stomata per 100 μm² (39.82 during 2019 and 37.07 during 2020), recorded under treatment T₈ closely followed by T₆ and the lowest found under control treatment (T₁). The very less duration for emergence of new leaf from culm was reported under treatment T₈. The highest stomatal index of black rice under treatment T₈ may be due to more availability of nutrients specially potassium along with some essential micronutrients, such as magnesium which will more essential for stomatal activities in leaf of black rice.

Phyllochron index

Table 3. Effect of different potassium management practices on chlorophyll content of black rice at PI and flowering stage

Treatment	Chlorophyll content (mg g ⁻¹ fresh leaf weight)											
	PI Stage						Flowering stage					
	Chlorophyll a		Chlorophyll b		Total chlorophyll		Chlorophyll a		Chlorophyll b		Total chlorophyll	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
T ₁	3.68	3.71	1.15	1.16	4.83	4.87	2.12	2.13	0.80	0.80	2.92	2.94
T ₂	4.05	4.08	1.18	1.20	5.23	5.28	2.18	2.19	0.82	0.82	3.00	3.01
T ₃	4.30	4.33	1.24	1.26	5.54	5.59	2.30	2.31	0.83	0.84	3.14	3.15
T ₄	4.22	4.24	1.22	1.23	5.44	5.47	2.28	2.30	0.83	0.83	3.11	3.14
T ₅	4.32	4.36	1.26	1.28	5.58	5.64	2.32	2.34	0.84	0.84	3.16	3.19
T ₆	4.54	4.59	1.42	1.44	5.96	6.03	2.44	2.46	0.95	0.95	3.39	3.41
T ₇	4.51	4.54	1.40	1.42	5.91	5.96	2.41	2.42	0.93	0.93	3.35	3.36
T ₈	4.56	4.62	1.45	1.47	6.01	6.09	2.46	2.49	0.95	0.95	3.41	3.45
T ₉	4.45	4.48	1.34	1.36	5.79	5.84	2.38	2.40	0.86	0.86	3.24	3.27
T ₁₀	4.41	4.44	1.31	1.33	5.72	5.77	2.35	2.37	0.85	0.86	3.21	3.23
T ₁₁	4.49	4.51	1.38	1.40	5.87	5.91	2.40	2.41	0.87	0.87	3.27	3.29
T ₁₂	4.34	4.39	1.29	1.30	5.63	5.69	2.33	2.34	0.84	0.85	3.18	3.19
SEm±	0.27	0.28	0.08	0.08	0.36	0.36	0.15	0.15	0.05	0.06	0.20	0.20
CD (P = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

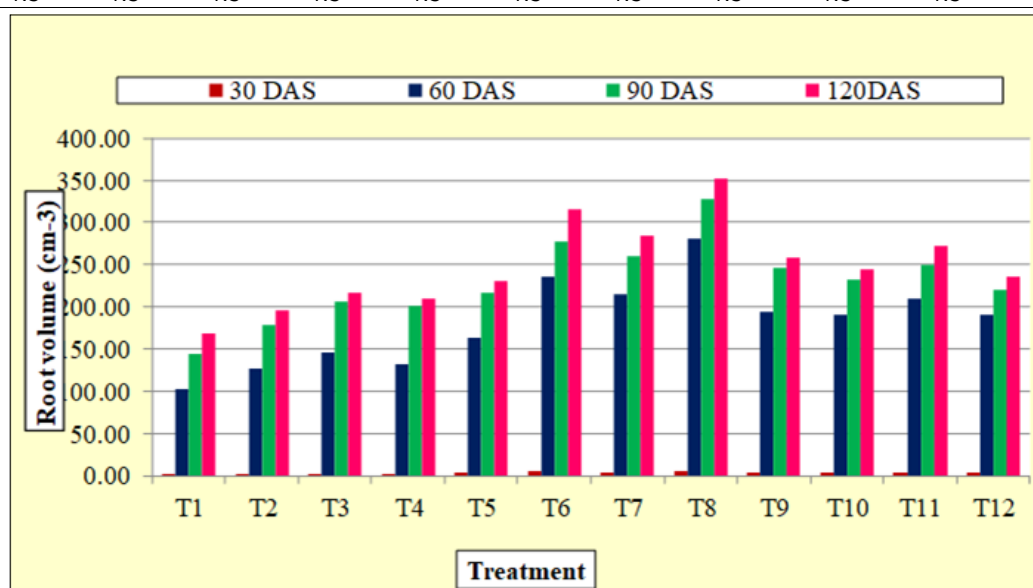


Fig. 3. Root volume (cm³) as influenced by different potassium management practices during 2019.

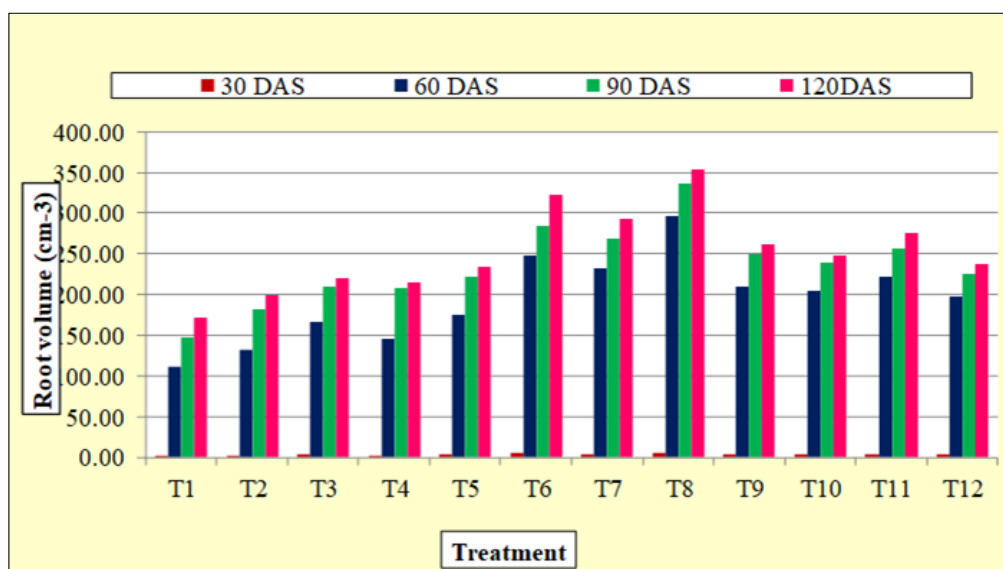


Fig. 4. Root volume (cm^3) as influenced by different potassium management practices during 2020.

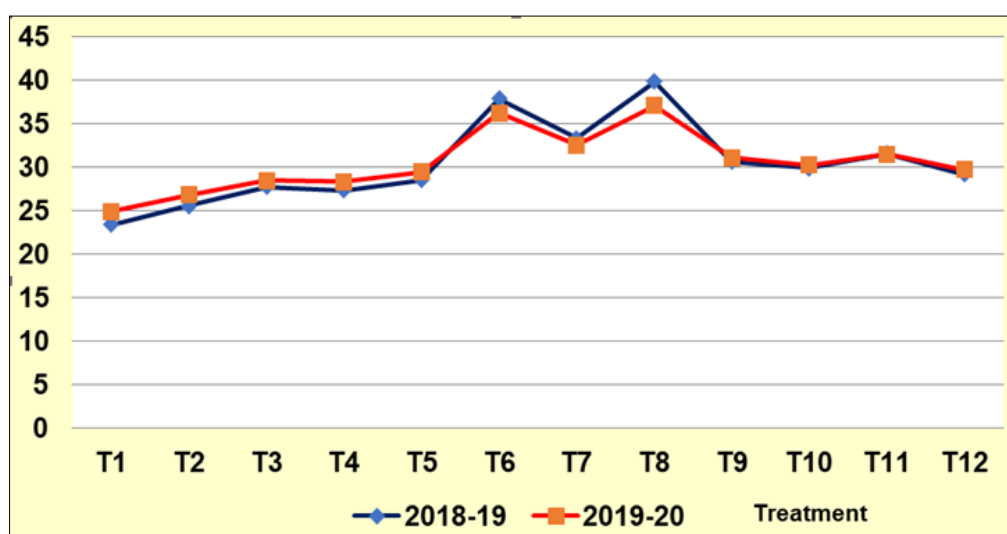


Fig. 5. Stomatal index of black rice as influenced by different potassium management practices during 2019 and 2020.

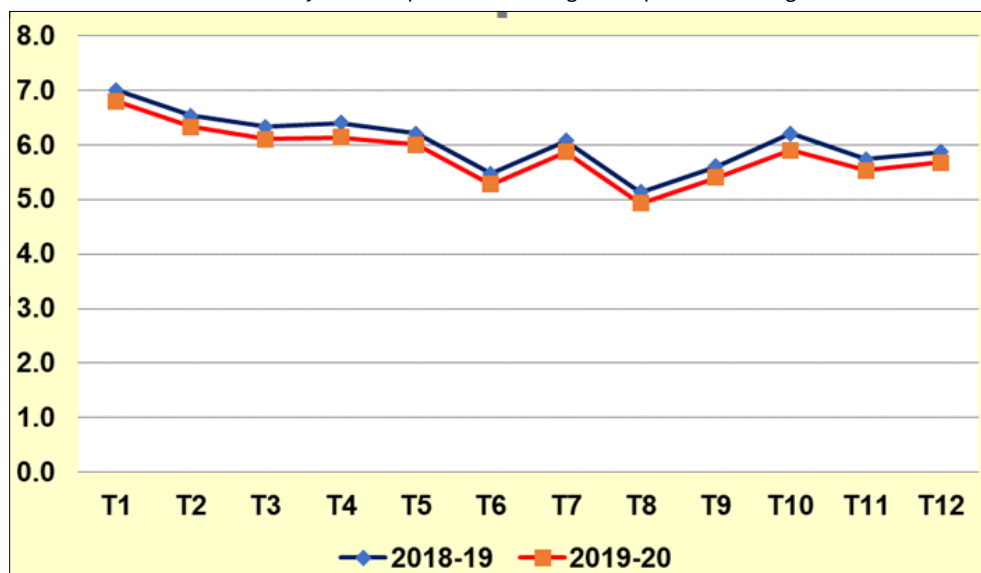


Fig. 6. Phyllochron index of black rice as influenced by different potassium management practices during 2019 and 2020.

Phyllochron index is an important phenological event of crop plant that determines the rate of leaf emergence or appearance interval between similar growth stages of successive leaves on the same culm. It was significantly influenced by different organic inputs during 2019 and 2020 (Fig. 6). The treatment T₈ had shown a

positive result on phyllochron index and this may be because of RDK through banana pseudo stem vermicompost which is a power house of many macro, micro and many essential enzymes, which help the crop to boost and enhance their growth and development.

Conclusion

The study concluded that potassium management significantly influenced the growth, yield and quality parameters of organic black rice under the acidic and nutrient-deficient soil conditions of Northeast India. The treatment involving RDK through banana pseudostem vermicompost combined with mustard oil cake (T_8) was most effective, enhancing key growth attributes such as leaf number, root traits, chlorophyll content and physiological indices, followed closely by *Azolla* incorporation with mustard oil cake (T_6). These treatments demonstrated the potential of organic potassium sources in improving black rice performance, underscoring their suitability for sustainable agriculture in organic systems. The control treatment (T_1) consistently yielded the lowest results, highlighting the importance of potassium supplementation. Future research should focus on evaluating the long-term effects of these organic potassium sources on soil fertility, nutrient cycling and grain quality, as well as exploring the integration of biofertilizers and advanced nutrient management approaches to further optimize black rice production under organic ecosystems.

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Authors' contributions

AD and JG have selected the research topic for research and prepared the framework of the research paper. AD collected all the field data, analyzed it and completed the paper writing. The final editing and proofreading were carried out by JG, KK, KD and RD. All the authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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