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Aerial spraying of nutrients and bio-fungicide for enhancing grain yield, grain quality and economics of rice in Kuttanad, Kerala

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Abstract
An experiment was carried out in two clusters of rice fields (polders) in Upper Kuttanad and North Kuttanad during November 2022 to February 2023 to investigate the effect of aerial foliar spray of nutrients and bio-fungicide on yield, grain quality and economics of paddy crop. Aerial spraying of treatments involving bio-fungicide, *Pseudomonas fluorescence* and macro nutrient formulation KNO_3 (13% N and 45% K) and secondary and micro nutrient mixture of Kerala Agricultural University, KAU Sampoorna multimix (Mg, S, B, Zn, Cu, Fe, Mn, Mo) was carried out at different crop stages alone or in combinations. Seven treatments *viz*., T1- Sampoorna (0.5%) @30 DAS, T2- KNO_3 (1 %) @80 DAS, T3- Sampoorna (0.5%) @30 DAS + KNO_3 (0.5%) @80 DAS, T4- Pseudomonas (2%) @30 DAS + Sampoorna (0.5%) @80 DAS, T5- Pseudomonas (2%) @30 DAS+ Sampoorna (0.5%) + KNO_3 (0.5%) @80 DAS, T6- Pseudomonas (2%) @ 70DAS + Sampoorna (0.5%) + KNO_3 (0.5%) @80 DAS, T7- No foliar spray, were applied randomly with three replications using unmanned aerial vehicle (drone). The foliar applications were carried out as a supplement to soil application of recommended dose of nutrients 90:45:45 kg NPK ha^{-1} and burnt lime as per Kerala Agricultural University package of practices recommendations. Observations on number of panicles, number of grains per panicle, test weight, percentage of blackened grains and grain yield were recorded and analysed with randomized completely block design. The effect of aerial spraying treatments was found to be significant on yield, test weight and percentage of blackened grains in field trials conducted in paddy fields of Upper Kuttanad and North Kuttanad. The treatments involving either KNO_3 applied at 80 days after sowing, coinciding with the flag leaf stage, alone or in combination with bio-fungicide or multi nutrient mix Sampoorna showcased better yield, grain quality attributes as well as the economics of rice crop.

Keywords: Rice, drone, aerial foliar spray, micro nutrient mixture, KNO_3, *Pseudomonas fluorescence*, grain quality

Introduction

Spread over about 55,000 ha, Kuttanad largely spans through three districts namely, Alappuzha, Kottayam and Pathanamthitta. Known as The Rice Bowl of Kerala, Kuttanad has the lowest altitude in India, and is also one of the few places in the world where cultivation takes place below sea level. While 65 per cent of the sub-sea-level farming is done in Alappuzha district, 30 per cent is done in Kottayam district and 5 per cent in Pathanamthitta district. The major agronomic zones of Kuttanad are Upper Kuttanad, Lower Kuttanad, North Kuttanad, Kayal Lands, Vaikom Kari and Purakkad Kari. The Upper Kuttanad is the slightly elevated land of the Kuttanad region covering an area of 10576 ha and North Kuttanad occupies the northern part of Kuttanad having an area of 6556 ha.

The soil of North Kuttanad and Upper Kuttanad in Kottayam district is extremely acidic with Fe and Al toxicity causing damage to plant roots during the critical period of panicle initiation or flowering. The major cropping season is from Oct- Nov to Jan-Feb and towards the later stages of the crop the rainfall will be less affecting the water quality which makes washing out the acidity through draining less effective, than the rainy season crop taken during June-July.

For the past ten years, the rice farmers of Upper and North Kuttanad have been facing grain discolouration or blackening of grains resulting in reduced yield as well as quality. The discolouration of rice grains is mainly attributed to the poor grain filling due to inadequate nutrient absorption by the damaged roots during the panicle initiation (PI) stage and post PI stage. The root damage due to Fe and Al toxicity is high towards the panicle initiation stage of the second season of the paddy crop in Kuttanad. Hence the uptake of nutrients is affected especially during and post panicle initiation stage. This results in blackening of grains as well as unfilled or chaffy grains. This is usually followed by secondary infection of grains by fungal pathogens which further deteriorate the grain quality. This hinders the paddy procurement process where private mills are bargaining with the farmers to reduce the price of paddy having a high percentage of discoloured grains.

During the post PI stage, the booting stage of the rice crop occurs, where flag leaves (boot leaves) are formed and they are the major source of nutrients to the emerging panicles. The flag leaf is the last to emerge indicating the transition from crop growth to grain production. Photosynthesis in this leaf provides the majority of the carbohydrates for grain filling. (Kalaichelvi, 2024) [3]. According to Mahesh *et al*. (2022) [8] flag leaf contributes 45% of rice grain yield because it mostly provides photosynthetic products to the panicle. If flag leaf is photosynthetically active with delayed senescence it will result in more photosynthates that can fill rice grain (Leng *et al*., 2017) [6]. In rice, 60 to 90 per cent of the total carbohydrates in the panicles at harvest are derived from photosynthesis after panicle initiation (Tari *et al*., 2009) [14]. Hence foliar application of nutrients can be effective for the absorption of nutrients to enhance the nutrient availability to panicles. Hence, nutrient spray at the post panicle initiation stage will result in immediate foliar

absorption of nutrients. This results in better grain filling and enhanced yield. Hence spraying of macro and micro nutrients are carried out by farmers for improving grain yield and grain quality. They also conduct spraying of highly priced chemical fungicide during the boot leaf stage for disinfecting the emerging panicles from fungal pathogens. This is bringing additional cost of spraying charges (ranging from Rs. 800 to 1000 acre^{-1}) to farmers. The recent advances in drone technology helps in the effective application of aerial spray in crops for efficient delivery of inputs to crops as well as reducing the cost of spraying. According to Singh *et al*. (2024) [11] drone spraying in agriculture is one of the most valuable tools, offering increased efficiency, reduced costs, and precise spraying capabilities. The uniform spraying of nutrients and other inputs as microdroplets ensures better intake of the same through leaves. Potassium is a major nutrient that is essential during flowering and grain filling in cereal crops like paddy. In addition to the crop root damage, the high Fe and Al toxicity of Kuttanad reduces the uptake of K^+ due to the differential absorption of Fe and Al. Hence, a study was conducted to find the effect of supplementing macro and micro nutrient as well as bio-fungicide application through unmanned aerial vehicle (UAV) to rice crop at different stages of growth on grain yield and grain quality attributes and economics of rice cultivation in farmers' fields in North and Upper Kuttanad in Kottayam district.

Materials and methods

An experiment was carried out in two clusters of rice fields (locally called 'padasekharam') in Nattakom Panchayat in Upper Kuttanad and in Vechoor panchayat in North Kuttanad and during November 2022 to February 2023 for investigating the effect of aerial foliar spray of nutrients and bio-fungicide on yield, grain quality and economics of paddy crop. The location of paddy field in Upper Kuttanad is 9°34'2.06"N and 76°25'47.9"E and North Kuttanad is 9°39'55.97" N and 76°25'7.34" E. The region has a tropical humid climate with clayey loam wetland soils in the paddy fields. The rice variety Uma (MO 16) a medium duration high yielding variety which is most popular among farmers of Kuttanad region was cultivated for the experiment. Aerial spraying of treatments involving bio-fungicide, *Pseudomonas fluorescence* @2% and macro nutrient formulation KNO_3 (13% N and 45% K) @0.5 % and secondary and micro nutrient mixture of Kerala Agricultural University, KAU Sampoorna multimix (Mg, S, B, Zn, Cu, Fe, Mn, Mo) @0.5% was used at different crop stages alone or in combinations were carried out. Seven treatments *viz*., T1- Sampoorna @30 DAS, T2- KNO_3 @80 DAS, T3- Sampoorna @30 DAS + KNO_3 @80 DAS, T4- Pseudomonas @30 DAS + Sampoorna @80 DAS, T5- Pseudomonas @ 30 DAS+ Sampoorna + KNO_3 @80 DAS, T6- Pseudomonas @ 70DAS + Sampoorna + KNO_3 @80 DAS, T7- No foliar spray, were applied randomly with three replications. Treatments involving foliar spraying of Sampoorna and KNO_3 at 80 DAS were done by mixing them together (as a mixture).

The plot size was 25 cents each where 10 kg sprouted seeds were uniformly broadcasted. All the plots were uniformly supplied with recommended dose of nutrients 90:45:45 kg NPK ha^{-1} as urea, rock phosphate and potash as well as burnt lime as per Kerala Agricultural University package of practices (KAU 2021) [4] as soil application. Observations on number of panicles, number of grains per panicle, test weight, percentage of blackened grains and grain yield were recorded. Statistical analysis was carried out with Randomized completely block design using GRAPES software of Kerala Agricultural University (Gopinath *et al*., 2020). The bio-fungicide *Pseudomonas fluorescence* was sprayed at 20 (early tillering stage) or 70 DAS (boot leaf stage) according to the treatments. Micronutrient mixture KAU Sampoorna for rice was sprayed at either 30 or 80 DAS (boot leaf stage) @0.5%. The macronutrient mixture with N (13%) and K (45%) was sprayed at 80 DAS only, @ 1% when used as a sole spray and @0.5% when used in combination with Sampoorna. The details including the specifications of aerial unmanned vehicle or drone used for aerial spraying used are given below

Table 1: Details of drone spraying

Parameters	Specifications
Model	FIA-QD10
Dimension	655×515×630mm- (arm and propeller folded) 1695×1795×630mm (arm and propeller unfolded)
Nozzle type	Flat fan
Tank capacity	10L
Spray width	4.5m
Spraying height	2m
No of nozzles	4
Time for spraying one acre	7min for plane land
Cost of spraying one acre	Rs.650/-

Results and discussion

The initial data on soil chemical properties show high soil OC percentage in both locations (Table 2.). The pH was strongly acidic in upper Kuttanad whereas it was very strongly acidic in North Kuttanad. The EC was below the critical limit of toxicity in upper and north Kuttanad. The available P was below the required limit and available K was sufficient in both locations.

Table 2: Data on initial soil chemical parameters of the farmers' fields

Farmers' field	OC (%)	pH	EC (dS m^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
Upper Kuttanad	1.5	5.2	0.442	7.92	138.09
North Kuttanad	1.89	4.8	0.377	4.02	277.23

After the harvest the soil chemical parameters changed and there was a slight reduction in soil OC values (Table 3). Soil pH values went down to very strongly acidic in both fields. The EC rose to 0.956 and 0.544 dS m^{-1} but was below the critical limit. The available P and K decreased after harvest in both regions.

Table 3: Data on post-harvest soil chemical parameters of the farmers' fields

Farmers' field	OC (%)	pH	EC (dS m^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
Upper Kuttanad	1.02	4.9	0.956	6.04	125.45
North Kuttanad	1.65	4.5	0.544	3.24	168.87

The effect of aerial spraying treatments was found to be significant on yield, test weight and percentage of blackened grains in field trials conducted in paddy fields of Upper Kuttanad (Table 4). The highest yield of 5.82 t ha^{-1} was recorded by T3- Sampoorna @30 DAS + KNO_3 @80 DAS. Next higher yield of 5.55 t ha^{-1} was recorded by the treatment T6- Pseudomonas @ 70DAS + Sampoorna + KNO_3 @80 DAS which was on par with T2- 13.00.45 @80 DAS (5.50 tha^{-1}) and T5- Pseudomonas @ 30 DAS+ Sampoorna + KNO_3 @80 DAS (5.42 tha^{-1}). The lowest grain yield was recorded for the treatment without any foliar spray (4.81 tha^{-1}). Next lower yield was followed by T1- Sampoorna @30 DAS. The test weight of 1000 grains was found to be the highest in T6 (23.83g) which was on par with T5 (23.67g) and the lowest being recorded in T7 (20.60g). The highest percentage of blackened grains was observed in treatment without foliar spray (T7) which was on par with T1 (Sampoorna @30 DAS). The lowest blackened grains percentage was recorded by T6- Pseudomonas @ 70DAS + Sampoorna + KNO_3 @80 DAS (15.61) which was on par with treatments (T5, T3, T4 and T2).

Table 4: Effect of aerial foliar spray treatments on the grain yield and grain quality attributes of rice cultivation in Upper Kuttanad

Treatments	Treatments	Yield (t ha^{-1})	No. of grains per panicle	No. of panicles	Test weight (g)	% of blackened grains
T1	Sampoorna @30 DAS	5.02^{d}	106.53	13.65	22.50^{bc}	21.35^{ab}
T2	KNO_3 @80 DAS	5.50^{b}	117.86	13.97	23.17^{ab}	20.06^{b}
T3	Sampoorna @30 DAS + KNO_3 @80 DAS	5.82^{a}	120.73	14.03	23.17^{ab}	17.11^{b}
T4	Pseudomonas @30 DAS + Sampoorna @80 DAS	5.25^{c}	119.84	13.23	22.17^{c}	19.56^{b}
T5	Pseudomonas @ 30 DAS+ Sampoorna + KNO_3 @80 DAS	5.42^{b}	113.67	14.13	23.67^{a}	17.01^{b}
T6	Pseudomonas @ 70DAS + Sampoorna + KNO_3 @80 DAS	5.55^{b}	117.33	14.00	23.83^{a}	15.61^{b}
T7	No foliar spray	4.81^{e}	100.23	14.03	20.60^{d}	27.89^{a}
Sem		0.054	4.43	0.634	0.217	2.223
CD		0.165	NS	NS	0.668	6.85

Similarly, in paddy fields of North Kuttanad, the effect of aerial spraying treatments was found to be significant on yield, number of grains per panicle, test weight and percentage of blackened grains in field trials conducted (|Table 5). Here the highest grain yield was found in T5- Pseudomonas @ 30 DAS+ Sampoorna + KNO_3 @80 DAS (5.90 t ha^{-1}) but was on par with T6- Pseudomonas @ 70DAS + Sampoorna + KNO_3 @80 DAS (5.85 tha^{-1}), T2 - KNO_3 @80 DAS (5.83 tha^{-1}) and T3- Sampoorna @30 DAS + KNO_3 @80 DAS (5.78 tha^{-1}). The number of grains per panicle was also found to be highest in T5 (126.44). The lowest grain yield (5.24 tha^{-1}) and number of grains per panicle (94.51) were recorded by treatment without foliar spray. The highest test weight of grains was observed in T6- Pseudomonas @ 70DAS + Sampoorna + KNO_3 @80 DAS (24.73g) followed by T2 (24.17g). The percentage of blackened grains were highest in T7 (33.23) and lowest in T6 (16.37).

Table 5: Effect of aerial foliar spray treatments on the grain yield and grain quality attributes of rice cultivation in North Kuttanad

Treatments		Yield (t ha^{-1})	No. of grains per panicle	No. of panicles	Test weight (g)	% of blackened grains
T1	Sampoorna @30 DAS	5.35^{b}	107.24^{bc}	16.15	23.33^{bc}	25.46^{b}
T2	KNO_3 @80 DAS	5.83^{a}	118.67^{ab}	15.11	24.17^{ab}	23.93^{bc}
T3	Sampoorna @30 DAS + KNO_3 @80 DAS	5.78^{a}	119.17^{ab}	15.27	23.00^{cd}	21.29^{cd}
T4	Pseudomonas @30 DAS + Sampoorna @80 DAS	5.55^{ab}	117.67^{ab}	15.13	22.00^{de}	21.60^{bc}
T5	Pseudomonas @ 30 DAS+ Sampoorna + KNO_3 @80 DAS	5.90^{a}	126.44^{a}	14.92	23.00^{cd}	17.4^{de}
T6	Pseudomonas @ 70DAS + Sampoorna + KNO_3 @80 DAS	5.85^{a}	118.68^{ab}	15.58	24.73^{a}	16.37^{e}
T7	No foliar spray	5.24^{b}	94.51^{c}	15.74	21.37^{e}	33.23^{a}
Sem		0.122	5.125	1.272	inf	1.291
CD		0.377	15.793	NS	1.007	3.977

The results clearly show the effect of macro nutrients N and K on the yield and grain quality of rice crop in both the locations. The initial soil parameters of both sites indicate the high acidity of the soil. Even though, the soils are high in organic carbon content the availability of N might have been restricted due to the poor mineralization of organic matter by the microorganism in acidic and anaerobic conditions. Most of the studies show low available N

content in Kuttanad soils in spite of the inherent high organic carbon content (Koruth *et al.*, 2013 [5] and Devi, 2021) [2]. The chemical fertilizers including N fertilizers were soil applied uniformly to all the treatments. However, the high acidity, Fe and Al toxicity and root damage prevent sufficient uptake of these nutrients by the plants especially during the critical stages of plant growth. This results in reduced grain yield and affects grain quality due to blackening or discolouration. The spraying of nutrients and bio-fungicides has enhanced the yield and grain quality compared to treatment without foliar application. Among the foliar spray treatments, the ones with spraying of N and K @ 80 DAS outyielded all other treatments.

The root damage due to Fe and Al toxicity is high towards the panicle initiation stage of the second season of the paddy crop in Kuttanad where rainfall is comparatively low. The Fe^{2+} ions are abundant in paddy fields and absorption of them by rice roots causes severe Fe toxicity. The rhizosphere of acid sulphate soils with pH less than 5 contains the massive amount of Fe^{2+} about 10–2,000 mg kg^{-1} (da Silveira *et al*., 2007) [1]. Ferrous toxicity inhibits cell division and elongation of the primary roots and subsequently the growth of lateral roots (Li *et al*., 2015). Hence, the uptake of nutrients is affected, especially during and post panicle initiation stage. The foliar application of macro and micronutrients at the flag leaf stage has helped in better nutrient absorption and resulted in better grain filling of the emerging panicles. A study by Shalini Pillai and Surya (2021) [9] revealed that FYM @ 5 t ha^{-1} along with 90:45:45 kg NPK ha^{-1} supplemented with flag leaf nutrition of potassium nitrate or 19: 19: 19 complex @ 0.5 per cent concentration, 5 days prior to booting and 50 per cent flowering stages elicited significantly superior physiological response in lowland rice. Singh and Prasad (2020) [10] reported that rice crop receiving K near grain filling had a higher number of filled grains and increased yield benefits when compared to corresponding treatments which received K only as basal. Also, Foliar K applications offer the opportunity to correct the deficiency, especially at latter growth stages when soil application may not be effective. Surendran *et al*., (2020) [12] found that soil test based NPK + foliar spray of KNO_3 (1 %) + Soluble boron (0.2%) 65 days after planting showed lower incidence of grain discoloration and gave 18.83 % more yield than that of farmers' practice. Swain *et al*. (2024) [13] stated that high concentration of ferrous ions in the soil solution disrupts the potassium balance in rice plants, leading to adverse effects on crop growth and a higher K dosage in iron-rich soil (pH-4.82, Fe-458.6 mg kg^{-1}) enhanced grain yield in rice.

The bio-fungicide spraying was carried out as a substitute for the high-priced chemical fungicides being applied by farmers during the boot leaf stage for disinfecting the emerging panicles from fungal pathogens.

The economics of rice cultivation in Upper Kuttanad due to the different aerial spray treatments are given in Table 3. The highest gross income (Rs 162960) was computed for T3, due to the highest yield obtained for the treatment. The lowest yield of T7 resulted in the lowest gross income (Rs 134680). The gross cost was found to be highest for T5 because it involves the cost of Pseudomonas 5 kg ha^{-1} (Rs80/kg) Sampoorna 1.25 kg ha^{-1} (Rs 115/0.5kg), KNO_3 1.25 kg ha^{-1} in combinations (75/0.5 kg) and two sprayings (Rs 3250 ha^{-1}) and the lowest for T7 (Rs 62500) which was followed by T1 (Rs 64412.5) where a single spray of Sampoorna was applied. The BCR was highest for T3 (2.45), followed by T6 (2.40), and BCR for the treatments were noticed in the following order T3>T6>T2>T5>T4>T1>T7.

Table 6: Effect of aerial foliar spray treatments on the economics of rice cultivation in upper Kuttanad

	Treatments	Gross income (Rs.ha^{-1})	Gross cost (Rs.ha^{-1})	Net income (Rs.ha^{-1})	BCR
T1	Sampoorna @30 DAS	140560	64412.5	76147.5	2.18
T2	KNO_3 @80 DAS	154000	64500	89500	2.39
T3	Sampoorna @30 DAS + KNO_3 @80 DAS	162960	66412.5	96547.5	2.45
T4	Pseudomonas @30 DAS + Sampoorna @80 DAS	147000	66437.5	80562.5	2.21
T5	Pseudomonas @ 30 DAS+ Sampoorna + KNO_3 @80 DAS	151760	66625	85135	2.28
T6	Pseudomonas @ 70DAS + Sampoorna + KNO_3 @80 DAS	155400	64625	90775	2.40
T7	No foliar spray	134680	62500	72180	2.15

Similarly, the economics of rice cultivation in North Kuttanad due to the different aerial spray treatments are given in Table 4. The highest and lowest gross income was recorded for T5 and T7 respectively, as a result of the highest and lowest yield of the treatments. The gross cost for the treatments was the same as in Table 3. The highest net income was found for T6and the lowest was for T7. The highest net income was found for T2 (Rs 98740.5) and T6 (Rs 99175) with the same BCR 2.53; both treatments involved KNO_3 spraying. The BCR was found to in the following order T2=T6>T5>T3>T7>T4>T1. Though the gross income for no foliar spray treatment (T7) was low, the higher cost of T4 and T1 resulted in slightly lower BCR than T7.

Table 7: Effect of aerial foliar spray treatments on the economics of rice cultivation in North Kuttanad

	Treatments	Gross income (Rs.ha^{-1})	Gross cost (Rs.ha^{-1})	Net income (Rs.ha^{-1})	BCR
T1	Sampoorna @30 DAS	149800	64412.5	85387.5	2.33
T2	KNO_3 @80 DAS	163240	64500	98740	2.53
T3	Sampoorna @30 DAS + KNO_3 @80 DAS	161840	66412.5	95427.5	2.44
T4	Pseudomonas @30 DAS + Sampoorna @80 DAS	155400	66437.5	88962.5	2.34
T5	Pseudomonas @ 30 DAS+ Sampoorna + KNO_3 @80 DAS	165200	66625	98575	2.48
T6	Pseudomonas @ 70DAS + Sampoorna + KNO_3 @80 DAS	163800	64625	99175	2.53
T7	No foliar spray	146720	62500	84220	2.35

The high acidity and Fe and Al toxicity prevalent in acid sulphate soils inhibit root growth and nutrient uptake during the critical stages like panicle initiation and flowering stages on rice crop. This often results in poor grain filling and secondary fungal infection of panicles during flowering and discolouration of rice grain. Hence the field study on management of the problem through aerial spraying of nutrients and or bio-fungicide through foliar application towards the tillering and the post panicle initiation stage was conducted. The study showed that the aerial spraying using KNO_3 alone or in combinations of bio-fungicide, *Pseudomonas fluorescence* and micro nutrient mix KAU Sampoorna at post panicle initiation stage resulted in significant improvement in yield and grain quality as well as profitability of rice in farmers' fields in Upper and North Kuttanad.

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