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Productivity of Paddies as Influenced by Varied Rates of Recommended Nutrients in Conjunction with Biofertilizers in Local Landraces

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Citation: Nataraja, T.H.; Naika, R.; Shankarappa, S.K.; Reddy, K.V.; Abdelmohsen, S.A.M.; Al-Harbi, F.F.; El-Abedin, T.K.Z.; Elansary, H.O.; Abdelbacki, A.M.M. Productivity of Paddies as Influenced by Varied Rates of Recommended Nutrients in Conjunction with Biofertilizers in Local Landraces. *Agronomy* **2021**, *11*, 1165. https://doi.org/10.3390/agronomy11061165

Academic Editors: Mauro Mori and Ida Di Mola

Received: 15 April 2021
Accepted: 1 June 2021
Published: 7 June 2021

Abstract: This research work explores the productive performance of local paddy landraces under different fertility levels as well as the role of microbial inoculants in improving the yields of paddy landraces and reducing nutrient additions by increasing nutrient use efficiency under changing climatic scenarios in coastal areas. The landrace *Padmarekha* recorded taller plants, more tillers per hill, higher total dry matter accumulation other than grain and straw yields besides better uptake of N, P_2O_5, K_2O, S and Zn. Further, nutrient management with the application of 100% of the recommended doses of fertilizers combined with biofertilizers including *Azospirillum* + *Bacillus megatherium* var. Phosphoticum + *Frateuria quaratia* + *Thiobacillus thiooxidans* + Vesicular Arbuscular Mycorrhiza recorded higher growth and yield traits in addition to improving the uptake of nutrients and partial factor productivity. Thus, it can be concluded that the application of 100% of the recommended dose of fertilizer, inoculated with biofertilizers, would be helpful in increasing the efficiency of applied nutrients in addition to improving yield and nutrient use efficiency.

Keywords: landraces; biofertilizers; yield; integrated nutrient management

1. Introduction

Rice (*Oryza sativa* L.) is a staple food crop of Asia that feeds more than half of the world's population with high calorific value (78.2% carbohydrate, 6.8% protein, 0.5% fat and 0.6% mineral matter) [1]. It is estimated that global rice production must reach at least 430 million tons by the year 2030 [2,3] and around 455 million tons by the year 2050 [4] to feed the growing population of the world.

Chemical fertilizers are the prime sources of nutrients in crop production systems. Increases in productivity of rice are often related to the use of synthetic fertilizers at an exponential rates [5]. However, the cost of chemical fertilizer application increases production costs [6,7]. In contrast, the reduction or elimination of subsidies on chemical fertilizers makes it hard for small farmers to manage money to fertilize crops [8]. Thus, the reduction in usage synthetic/chemical fertilizers is the major concern of the day. In addition, the massive application of fertilizers in crop production has resulted in environmental changes. For example, rice crops sparsely use only 20–30% of applied N, while the other 20–30% remains in the soil at crop harvest, and the rest is lost through the gaseous form of ammonia, causing a global pollution risk [9,10]. Thus, it is the need of the hour to find an alternative means to supplying nutrients to reduce dependency on chemical fertilizers in rice crops and improve the efficiency of applied fertilizers without any environmental pollution. Chemical fertilizers initially increase yields but slowly deteriorate soil and reduce fertility, creating soil nutritional problems. Long term use of NPK fertilizers has resulted in soil salinity and nutrient imbalances [11]. Erratic use of chemical fertilizers has not only reduced soil health but also has decreased yields of rice crops by 38% [2,12]. Fertilizer usage in conventional rice cultivation is reported to have less efficiency of applied nutrients due to the improper use of water and the readily available nature of very fragile nutrient ionic forms present in fertilizers [8]. Rice production systems have increased their dependence on chemical fertilizers over a few decades, leading to the depletion of soil fertility and other soil-related constraints [7]. Due to over-exploitation of resources, the deficiency of several nutrients has become a major issue. There is a need to re-look at principles and practices to preserve soil health, sustain production systems and provide quality food for meeting nutritional requirements. Conventional nutrient sources are mostly used for maintaining soil health and quality in the traditional rice production systems. These are locally available in their farm lands through the outputs subsidiary enterprises which generates organic nutrients sources like farm yard manure, compost, crop residues etc which helps in reducing the cost of nutrient management. On the contrary, the increase in demand for organic nutrient sources have increased which are not matching the nutrient requirement of the crops and supply through alternative sources in the market.. Hence, adopting an integrated approach is needed for meeting crop nutrient demands in addition to addressing current pollution problems. Thus, it is imperative to adopt strategies for effective utilization of land and water in addition to the practical application of organic and mineral fertilizers, helping to attain sustainability in rice production [5]. Integrated nutrient management involves the application of synthetic fertilizers, organic sources and bio-inoculants to manage nutrient demand, and helps in achieving higher yields [13]. Biofertilizer usage is in demand for sustained production and better resource utilization in integrated nutrient management. It is a cheaper source that has gained momentum in the recent past and played a key role in maintaining long term soil fertility and sustainability [14]. Hence, new cultivation strategies with the use of biofertilizers are required for crop yield improvement along with the preservation of soil health [15]. Biofertilizers were formulated based on the beneficial effects of microorganisms on crop growth [16,17]. These are applied as supplements to chemical fertilizer in sustainable agriculture [1]. The integrated use of biofertilizers in rice offers an inexpensive and eco-friendly route to boosting rice productivity.

Biofertilizers help in fixing atmospheric nitrogen or mobilizing or converting insoluble phosphate, potassium and sulfate in the soil into forms available to plants [18], perhaps increasing the interest of modern agronomists. Nitrogen-fixing bacteria, or diazotrophs, association with rice crops is one substitute that has been used to replace part of the N fertilizer and also help the plant access other added or naturally available nutrients present in the soil [19]. Usually, N-fixing and P-solubilizing inoculants are important biofertilizers used in rice crops [1]. These are used as seed treatments, for seedling dipping or for soil application. Nowadays, the multi-strain biofertilizers available have more efficacy than single-strain biofertilizers, as they fix atmospheric nitrogen and simultaneously increase the bioavailability of phosphorus. Furthermore, biofertilizers containing many strains are found to increase growth by 15–50%, as compared to chemical fertilizers. [20,21]. Improvement of soil nutrient dynamics in terms of solubility of nutrients mainly soil

P, absorption and uptake of nutrients by plants and alleviation of plant stress besides improving soil fertility is reported with the use of vesicular arbuscular mycorrhizal (VAM) fungi in many crops [22,23]. With the increase in awareness of biofertilizers, the production of biofertilizers has been constantly increasing in India, from a mere 2000 t in 1992–1993 to 65,500 t in 2013–2014 [24,25].

In Karnataka, more than 50% of the rice area grown is covered with traditional land races. A wide variety of the rice germplasm is available and being utilized successfully in rice breeding programs. The, traditional landraces are grown by the famers as it possess valuable traits like aroma, abiotic stress, submerge tolerance, uniqueness in taste, nutrition, medicinal properties and productivity that is on par with high-yielding varieties [26]. The productivity of paddy landraces in coastal climates is comparatively lower than their potential yield. This might be due to inadequate and improper nutrient management practices. In addition to this the precipitation in costal area is higher which causes leaching of nutrients such as nitrogen, potassium. Further the other nutrients imbalances like phosphorus fixation due to soil acidity, micronutrient deficiencies lead to deteriorate soil fertility affecting the yield of rice. Therefore, these traditional landraces might have acted as a "selective filter" on the associated nutrient fixing/mobilizing bacterial population such that only more efficient genotype/bacteria interactions were established over the years. In the present study, we used the complementary options of using microbial consortia for N-fixing and P, K and S-solubilizing microbial inoculants, mainly for increasing effeicency of applied nutrients besides increasing productivity [1,16,21]. The studies on nutrient management with microbial inoculants along with mineral fertilizers in coastal areas for cultivating traditional landraces of rice, is limiting. Thus, technological innovation with respect to nutrient management by integrating different nutrient sources for improving nutrient use efficiency is essential to increase productivity of paddies in coastal areas. Thus, keeping these points in view, the present investigation was carried out in farmers' fields in the coastal climate of Mirjan village of the Kumta Taluk, Uttara Kannada district of Karnataka, India to study the impact of biofertilizer and chemical fertilizer combinations on the growth and development of local paddy landraces.

2. Materials and Methods

2.1. Experimental Site

A field experiment was conducted in the rainy seasons during 2017 and 2018 in farmers fields' in Mirjan village, Kumta Taluk, Uttara Kannada district (Karnataka), India located at 14°42′33.8″ northern latitude and 74°4′27.6″ eastern longitudes. It is representative of agro–ecological sub-region 19.3 of Zone 10, covering a coastal area of around 350 km [27] and with an elevation of 603 m above mean sea level. The climate is tropical, strongly influenced by the monsoons as a source of precipitation. During the monsoons, the region receives one of the heaviest rainfalls in India, averaging 2877 mm.

2.2. Soil Characteristics

The soil of the experimental site was loamy sand in texture. Soil samples from 0–30 cm depth from the soil surface were randomly collected before land preparation and analyzed for various physicochemical properties during both growing seasons. Moisture content at field capacity was 17.5 percent at the 0–15 cm layer, with a bulk density of 1.46 g cc^{-1}. The soil was acidic (pH 5.34), and electrical conductivity was 0.05 dS m^{-1}. The organic carbon content was 1.66 percent. The available nutrient content was nitrogen (442.5 kg ha^{-1}), phosphorus (9.2 kg ha^{-1}), potassium (105.5 kg ha^{-1}), sulfur (19 ppm) and zinc (13 ppm).

2.3. Experiment Details

The experiment was laid out in a split plot design with 24 treatment combinations and 3 replications, with a plot size of 8.0 m × 5.0 m. The main plots (M) consisted of six paddy landraces, M_1-*Hal doddiga*, M_2-*Mysore sanna*, M_3-*Padmarekha*, M_4-*Halga*, M_5-*Kemp jadda bhatta* and M_6-*Kari kagga*. In subplot (S), there were four different biofertilizer and chemical fertilizer combinations, taken for study as follows: S_1 = farmer's practice, S_2 = 50% recommended dose of fertilizers (RDF) + biofertilizers (Azospirillum + *Bacillus megatherium* var. Phosphoticum + *Frateuria quaratia* + *Thiobacillus thiooxidans* + VAM), S_3 = 75% RDF + biofertilizers and S_4 = 100% RDF + biofertilizers.

The biofertilizers used were *Azospirillum* as free-living N fixers, *Bacillus megatherium* var. Phosphoticum as phosphate-solubilizing microorganisms, *Frateuria quaratia* as K mobilizers, *Thiobacillus thiooxidans* as S solubilizers and the fungi Vesicular Arbuscular Mycorrhiza (VAM). The seedlings were dipped in the inoculated solution of the above-mentioned inoculants before transplanting. The biofertilizers were obtained from the state Department of Agriculture, Uttara Kannada district, Karnataka.

The farmer's practice was comprised of the application of 100 kg complex fertilizers (15:15:15), 50 kg muriate of potash and 1.5 tons of farm yard manure without application of zinc sulfate, lime and biofertilizers at the time of transplanting. Further, 50 kg urea is applied as top dressing at 30 days after transplantingand other agronomic practices were the same as the treatment plots. The farmer's practice adopted in the experiment were based on the methods of nutrient management practice followed by the farmers in the region. This helped to compare the improvements in productivity of the rice and the effects of different microbial inoculants under different fertility levels.

2.4. Crop Husbandry Practices

The field was prepared through conventional tillage to a depth of 15 cm with one ploughing and two harrowings, followed by puddling after the application of 10 and 12 cm depths of water, respectively, in the first and second years. The puddled plain land was divided into three blocks, with 24 treatment combinations in each block. Well-decomposed farmyard manure as per the required amounts in the specific treatments was added 15 days before transplanting.

A fertilizer dose of $N:P_2O_5:K_2O$ at 75:75:90 kg/ha was given in two split doses, as per the University of Agricultural Sciences, Dharwad recommendation. Urea, diammonium phosphate (DAP), and muriate of potash (MOP) were used as fertilizers to feed the crops in all the treatments except the farmer's practice (control). Full quantities of P_2O_5 and K_2O and 50% N Fertilizer were given at the time of sowing, and 50% N at the tillering stage. The fertilizers $ZnSO_4$ 25 kg ha^{-1}, farmyard manure (FYM) 5.0 t ha^{-1} and lime 500 kg ha^{-1} were applied to all the treatments except the farmer's practice before transplanting. Seedlings were raised in nursery beds, and 21 days old 2–3 seedlings per hill were transplanted to the main field., with a spacing of 20 cm between rows and 10 cm between plants within rows. Before transplanting, seedlings of the respective treatments were inoculated with biofertilizer slurry at the rate of 5 kg each per hectare for eight hours. However, the control plots were transplanted with uninoculated seedlings.

2.5. Data Collection

Data on Crop Traits

The observations were recorded at harvest to assess crop growth impacts. The data on crop traits, uptake of nutrients and soil nutrient status after harvest of crop were tabulated and subjected to statistical analysis.

Agro-morphological traits were measured following the standard evaluation system of IRRI [28]. The traits measured were crop phenology tillering (total tiller number $plant^{-1}$), plant height, biomass yield and grain and straw yield. Five observation plants were tagged, and periodical observations were recorded from the same plants and expressed as the mean of five plants. Tillering was recorded by counting the number of tillers in a hill. The plant height (i.e., the height of the rice plant from the node separating root and shoot up to the tip of the panicle) was measured using a meter- and centimeter-graduated, flexible metal ruler. The plant samples were collected from the border rows for destructive sampling such as dry matter accumulation and distribution and were shade dried for few days, followed by oven drying at 70 °C for 48 h until a constant weight was obtained. The dry matter was expressed as g plant^{-1}.

At physiological maturity, random plant samples from each plot were harvested manually and separated into straw and panicles. The dry weight of straw was determined after oven drying at 70 °C for 48 h to a constant weight. Panicles were hand-threshed, and the filled spikelets were separated from unfilled spikelets with a blower. Grain yield was determined from each net plot and adjusted to the standard moisture content of 14% moisture. Biomass yield was calculated as the sum of the straw or the vegetative parts' weight and the seed/grain weight.

Soil organic carbon was estimated by the wet digestion method of Walkely and Black [29]. Available N content in the soil was determined by the alkaline permanganate method as described by Subbiah and Asija [30]. Available P was determined by the Bray II method [31]. Available K was extracted by 1 M ammonium acetate (pH = 7.0) and determined by flame photometry [32].

In the plant samples, the grain and straw were analyzed for N content by the Micro Kjeldahl method and digested in a di-acid mixture (10:1) with 10 parts of sodium sulfate and 1 part of copper sulfate. A further 0.25 g sample was digested in a tri-acid mixture comprising HNO_3, HSo and HClO (perchloric acid) in a 10:1:4 proportion, and phosphorus was determined colorimetrically using the vandomolybdate phosphate yellow color complex. Potassium was estimated through a flame photometer [33]. Sulfur content was determined by the turbidimetric method [34], and zinc was estimated by atomic absorption spectrometer (AAS), using the DTPA extractant [35].

The nutrient uptake was calculated using the formula [1]

$$\text{Nutrient Uptake}\left(\text{kg ha}^{-1}\right) = \frac{\text{Nutrient concentration }(\%)}{100} \times \text{ Biomass}\left(\text{kg ha}^{-1}\right).$$

2.6. Statistical Analysis

The data from the experiment was tested for normal distribution and was statistically analyzed using the F-test as outlined by Gomez and Gomez, 1984 [36]. Least significant difference (LSD) values (p = 0.05) were used to determine the significance of the difference among treatment means.

Any outliers within the dataset were verified using standardized residual plots, which were composed of normal probability plots and plots with residuals versus fitted values of the response variables. The least square means of factors were separated using the Tukey–Kramer test at a level of significance of 5% in collaboration with colleagues from King Saud and Princess Nourah bint Abdulrahman Universities.

The data from two seasons was tested for homogeneity of variance, and pooled analysis was performed to identify the effects of treatments over seasons. The significant difference among treatments was identified using LSD at p = 0.05 to draw suitable interpretations [37].

3. Results and Discussion

3.1. Influence on Growth and Yield of Traditional Paddy Landraces under Different Fertility Levels and Biofertilizers

Plant–microbe interactions in the rhizosphere are deciding factors for plant growth and soil health and sustainability. The present study revealed that growth and yield of different local landraces were significantly influenced by the application of different biofertilizers under different fertility levels. Significantly higher grain and straw yield was recorded with the landrace *Padmarekha*, with a mean yield of 6.62 t ha^{-1} and 7.47 t ha^{-1} respectively. Further, the other landraces *Hal doddiga* (6.36 t ha^{-1} and 7.4 t ha^{-1}), *Halga* (6.30 t ha^{-1} and 7.28 t ha^{-1}), *Kemp jadda bhatta* (6.30 t ha^{-1} and 7.3 t ha^{-1}) and *Mysore sanna* (6.21 t ha^{-1} and7.33 t ha^{-1}) were on par with each other, and the genotype *Kari kagga* (4.62 t ha^{-1} 5.8 t ha^{-1}) recorded the significantly lowest grain and straw yield. The application of biofertilizers along with various levels of recommended doses of fertilizers had significant influence on the growth and yield of paddy landraces. The highest yield of 6.70 t $ha^{-1}$was recorded with the application of 100% RDF + *Bacillus megatherium* var. Phosphoticum + *Frateuria quaratia* + *Thiobacillus thiooxidans* + VAM. The interaction effects of paddy landraces with RDF and biofertilizers differed significantly with respect to grain yield. The yield of all the genotypes performed steadily higher under the treatment with the application of 100% RDF with biofertilizers (*Bacillus megatherium* var. Phosphoticum + *Frateuria quaratia* + *Thiobacillus thiooxidans* + VAM) over both years (Table 1). The role of biofertilizers in enhanced plant growth has been shown due to their ability to produce high quantities of growth-promoting substances [23]. In addition, microorganisms and VAMhave the potential to fix N and for P and K mobilization, solubilizing S and Zn and leading to enhanced nutrient uptake [21].

The variety *Padmarekha* recorded significantly higher total dry matter (52.2 g $hill^{-1}$) at harvest over the other landraces such as *Mysore sanna* (51.88 g $hill^{-1}$), *Hal doddiga* (49.67 g $hill^{-1}$), *Halga* (48.93 g $hill^{-1}$), *Kemp jaddabhatta* (47.98 g $hill^{-1}$) and *Kari kagga* (38.45 g $hill^{-1}$). The higher dry matter accumulation of *Padmarekha* may be attributed to higher growth and yield traits at harvest as a result of better utilization of light and nutrients as compared to other landraces. The increase in dry matter and yield could be due to effective utilization of added and released nutrients through biofertilizers in addition to the inherent nutrients from the soil. The, increas in biological activity of the plant system leading to increases in crop height and the tillering ability of plants due to accumulation and distribution of plant dry matter [38,39] promoted higher physiological activity [40,41] promoting the production and synthesis of auxins such as indole acetic acid [1,21,23] ehnahced the growth of rice plants.

Th application of biofertilizers along with chemical fertilizers significantly influenced the grain yield in landraces. Application of 100% RDF along with biofertilizers recorded 20% higher grain yield (6.70 t ha^{-1}) compared to the farmer's practice (5.34 t ha^{-1}), while it recorded 13% and 5% yield improvement over 50% RDF + biofertilizers (5.86 t ha^{-1}) and 75% RDF + biofertilizers (6.37 t ha^{-1}), respectively (Table 1). Significant yield increase with 100% RDF along with biofertilizers was mainly due to increased yield traits like number of spikelets per panicle, panicle weight, number of grains per panicle, panicle length and test weight, total dry matter production and nutrient uptake [42,43]. Few researchers have also opined that the application of different sources of nutrients (organic and inorganic) to paddies has the advantage in terms of higher yield, nutrient and water use efficiency of the paddy [8].

Table 1. Growth and yield of traditional paddy landraces as influenced by different fertilizer levels in conjunction with biofertilizer practices in the coastal areas of Kumta Taluk, Uttara Kannada district, Karnataka, India.

Varieties	Plant Height (cm)			No. of Tillers per Hill			Total Dry Matter (g hill^{-1})			Grain Yield (t ha^{-1})			Straw Yield (t ha^{-1})		
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
M_1: *Hal doddiga*	112	111 **	**112**	13.9	14.2 **	**13.9**	49.4	50.0 **	**49.7**	6.40 **	6.31 **	**6.36 ****	7.45 **	7.35 **	**7.40 ****
M_2: *Mysore sanna*	113	112 **	**113**	14.2 **	14.5 **	**14.2 ****	53.9 **	49.9	**51.9 ****	6.31	6.12	**6.21 ****	7.46 **	7.20	**7.33 ****
M_3: *Padmarekha*	118 **	115 **	**116 ****	14.7 **	15.1 **	**14.7 ****	52.0 **	52.4 **	**52.2 ****	6.70 **	6.54 **	**6.62 ****	7.39 **	7.54 **	**7.47 ****
M_4: *Halga*	110	106	**108**	13.7	13.1	**13.7**	48.6	49.3	**48.9**	6.36 **	6.24 **	**6.30 ****	7.41 **	7.15	**7.28 ****
M_5: *Kemp jadda bhatta*	116 **	112 **	**114 ****	13.9	13.6	**13.9**	47.6	47.4	**47.5**	6.39 **	6.21	**6.30 ****	7.21 **	7.40 **	**7.30 ****
M_6: *Kari kagga*	101	101	**101**	9.0	8.5	**9.0**	38.5	38.4	**38.5**	4.52	4.71	**4.62**	5.68	5.92	**5.80**
Mean	**112**	**109**	**111**	**13.2**	**13.2**	**13.2**	**48.34**	**47.87**	**48.1**	**6.12**	**6.02**	**6.07**	**7.10**	**7.09**	**7.10**
S.Em±	**0.9**	**1.2**	**0.7**	**0.13**	**0.35**	**0.13**	**0.68**	**0.53**	**0.36**	**0.10**	**0.08**	**0.06**	**0.14**	**0.08**	**0.06**
LSD (p = 0.05)	**3.3**	**4.2**	**2.6**	**0.47**	**1.29**	**0.47**	**2.47**	**1.94**	**1.32**	**0.35**	**0.30**	**0.23**	**0.52**	**0.27**	**0.24**
Fertilization levels															
S_1: Farmer's practice	99	96	**97**	10.1	9.9	**10.1**	20.8	21.2	**21.0**	5.50	5.18	**5.34**	6.17	6.16	**6.17**
S_2: 50% RDF + biofertilizers	110	109	**109**	13.1	13.3	**13.1**	49.4	48.7	**49.1**	5.85	5.87	**5.86**	6.88	7.00	**6.96**
S_3: 75% RDF + biofertilizers	117	116 **	**117 ****	14.6 **	14.4 **	**14.6 ****	58.6	59.0	**58.8**	6.37	5.87	**6.37**	7.56 **	7.34 **	**7.55 ****
S_4: 100% RDF + biofertilizers	121 **	117 **	**119 ****	15.1 **	14.9 **	**15.1 ****	64.5 **	62.6 **	**63.5 ****	6.74 **	6.38 **	**6.70 ****	7.79 **	7.58 **	**7.72 ****
Mean	**112**	**109**	**111**	**13.2**	**13.2**	**13.2**	**48.34**	**47.87**	**48.1**	**6.12**	**6.02**	**6.07**	**7.10**	**7.09**	**7.10**
S.Em±	**1.1**	**1.5**	**1.8**	**0.25**	**0.46**	**0.28**	**0.63**	**0.79**	**0.54**	**0.06**	**0.07**	**0.05**	**0.10**	**0.09**	**0.07**
LSD (p = 0.05)	**3.1**	**4.2**	**2.6**	**0.73**	**1.34**	**0.82**	**1.83**	**2.29**	**1.56**	**0.18**	**0.22**	**0.13**	**0.27**	**0.26**	**0.20**
Interaction (M × S)															
S.Em±	**2.2**	**2.9**	**1.8**	**0.51**	**0.93**	**0.57**	**1.27**	**1.81**	**1.08**	**0.13**	**0.15**	**0.09**	**0.19**	**0.18**	**0.14**
LSD (p = 0.05)	**NS**	**NS**	**NS**	**1.46**	**2.67**	**1.64**	**3.66**	**NS**	**3.13**	**NS**	**0.43**	**0.27**	**NS**	**NS**	**NS**

Note: Biofertilizers included *Azospirillum* + *Bacillus megatherium* var. Phosphoticum + *Frateuria quaratia* + *Thiobacillus thiooxidans* + *Vesicular Arbuscular Mycorrhiza.* Farmer's practice included only application of NPK, as mentioned in the methodology, without any biofertilizers; ** refers to significant at p = 0.05. The pooled average mentioned in the table in bold numbers.

The application of biofertilizers and vermicompost at 5.0 t ha^{-1}, along with the chemical fertilizers, had a positive influence on the growth and yield attributes of rice [44]. Significantly higher total dry matter per hill was recorded with 100% RDF along with biofertilizers (63.5 g $hill^{-1}$) at harvest as compared to the farmer's practice (20.99 g $hill^{-1}$), 50% RDF + biofertilizers (49.1 g $hill^{-1}$) and 75% RDF + biofertilizers (58.8 g $hill^{-1}$). Application of biofertilizers along with chemical fertilizers comprising of NPK and Zn helped in the stable availability of nutrients in the soil solution pools at all stages, which promoted the effective growth of crops and dry matter production in addition to grain and straw yield [45–47]

In addition to growth and development, improved soil aggregation, higher quantities of nutrient availability and enhanced soil microbial activity, resulting in congenial soil conditions, with a consequent improved uptake of nutrients, have led to more vegetative growth of plants and also higher dry matter [45,48]. Increased total dry matter influenced the higher straw and grain yield. The accumulation of higher dry mater might be due to the increase in the number of tillers per hill produced through with physiologically active green leaves provided scope for increased photosynthetic activity [49–51].

A significantly higher plant height of 119 cm at harvest was recorded with 100% RDF along with biofertilizers as compared to the farmer's practice (97 cm), 50% RDF along with biofertilizers (109 cm) and 75% RDF along with biofertilizers (116 cm) at harvest (Table 2). The increase in plant height could be attributed to the greater availability, accelerated or steady release of nitrogen with the influence of the *Azospirillum* supplied to the crop through root inoculation. This was compatible with the rhizosphere of the traditional landraces of the paddies, providing an opportunity for greater nutrient acquisition with the help of microorganisms applied to the crop [41]. Several workers reported that an adequate supply of plant nutrients through organic manures, biofertilizers and mineral nutrietns influenced plant growth and yield related to the greater release of nutrients during successive crop growth stages by organic sources of nutrients [52,53] including biofertilizers [46]. The long-term application of organic nutrient sources can enable a better environment for plant growth by maintaining soil quality and sustaining the yields of rice crops in coastal region [54].

Table 2. Yield attributes of traditional paddy landraces as influenced by different fertilizer levels in conjunction with biofertilizer practices in coastal areas of Kumta Taluk, Uttara Kannada district, Karnataka, India.

Varieties	**Productive Tillers per Hill**			**Panicle Length (cm)**			**Grain Weight (g spike^{-1})**			**No. of Grains per Panicle**			**Test Weight (g)**		
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
M_1: *Hal doddiga*	13.6	14.2	**13.9** **	21.8 **	22.3	**22.1**	3.88	4.03	**3.96** **	120.8 **	122.7 **	**121.8** **	24.9 **	25.3 **	**25.1** **
M_2: *Mysore sanna*	14.0	14.6 **	**14.3** **	22.2 **	22.7	**22.5** **	3.68	3.83	**3.76**	120.2 **	122.0 **	**121.1** **	23.9	24.3	**24.1**
M_3: *Padmarekha*	14.4	15.0 **	**14.7** **	23.0 **	23.5 **	**23.2** **	4.21 **	4.36	**4.28** **	125.0 **	126.9 **	**125.9** **	26.0 **	26.4 **	**26.2** **
M_4: *Halga*	13.3	13.9	**13.6**	21.4 **	21.9	**21.7**	3.71	3.86	**3.78**	117.6 **	119.2	**118.4**	23.1	23.5	**23.3**
M_5: *Kemp jadda bhatta*	13.3	13.9	**13.6**	21.1	21.6	**21.3**	3.71	3.84	**3.77**	116.4 **	118.1	**117.3**	22.6	23.0	**22.8**
$M_{6:}$ *Kari kagga*	11.4	12.0	**11.7**	16.1	16.6	**16.4**	3.21	3.36	**3.28**	90.7	92.6	**91.7**	18.0	18.4	**18.2**
Mean	**13.32**	**13.92**	**13.62**	**20.93**	**21.43**	**21.18**	**3.73**	**3.88**	**3.81**	**115.13**	**116.90**	**116.01**	**23.08**	**23.48**	**23.28**
S.Em±	0.43	0.16	**0.26**	0.48	0.14	**0.25**	0.05	0.22	**0.13**	3.50	1.72	**1.40**	0.48	0.49	**0.31**
LSD (*p* = 0.05)	NS	0.59	**0.96**	1.75	0.50	**0.92**	0.17	NS	**0.48**	12.72	6.25	**5.10**	1.75	1.78	**1.11**
Fertilization levels															
S_1: Farmer's practice	10.9	11.5	**11.2**	17.40	17.90	**17.7**	2.63	2.78	**2.71**	91.29	92.91	**92.1**	18.75	19.15	**19.0**
S_2: 50% RDF + biofertilizers	12.5	13.1	**12.8**	**19.6**	**20.1**	**19.8**	3.73	3.88	**3.80**	113.7	115.6	**114.7**	21.05	21.45	**21.3**
S_3: 75% RDF + biofertilizers	14.6 **	15.2	**14.9**	22.8	23.3	**23.0**	4.12	4.27	**4.20**	125.1 **	126.9	**126.0**	24.65	25.05	**24.9**
S_4: 100% RDF + biofertilizers	15.3 **	15.9 **	**15.6** **	24.0 **	24.5 **	**24.3** **	4.45 **	4.59	**4.50** **	130.4 **	132.2 **	**131.3** **	27.85 **	28.25 **	**28.1** **
Mean	**13.32**	**13.92**	**13.62**	**20.93**	**21.43**	**21.18**	**3.73**	**3.88**	**3.81**	**115.13**	**116.90**	**116.01**	**23.08**	**23.48**	**23.28**
S.Em±	0.34	0.17	**0.19**	0.59	0.13	**0.31**	0.06	0.13	**0.07**	2.08	1.52	**1.20**	0.59	0.55	**0.41**
LSD (*p* = 0.05)	0.98	0.50	**0.55**	1.70	0.37	**0.90**	0.17	0.37	**0.20**	6.00	4.39	**3.46**	1.70	1.58	**1.18**
Interaction (M × S)															
S.Em±	**0.68**	0.35	**0.38**	1.18	0.25	**0.62**	**0.12**	0.25	**0.14**	4.16	3.04	**2.39**	**1.18**	1.09	**0.82**
LSD (*p* = 0.05)	NS	NS	**NS**	NS	0.74	**1.80**	NS	NS	**NS**	NS	NS	**NS**	NS	NS	**NS**

Note: Biofertilizers included *Azospirillum* + *Bacillus megatherium* var. Phosphoticum + *Frateuria quaratia* + *Thiobacillus thiooxidans* + *Vesicular Arbuscular Mycorrhiza.* Farmer's practice included only application of NPK, as mentioned in the methodology, without any biofertilizers; ** refers to significant at p = 0.05. The pooled average mentioned in the table in bold numbers.

3.2. Influence on Nutrient Uptake under Different Fertility Levels and Biofertilizer Applications in Traditional Paddy Landraces

Significantly higher nutrient uptake was observed in *Padmarekha* (104.08 kg N ha^{-1}, 33.96 kg P_2O_5 ha^{-1}, 111.81 kg K_2O ha^{-1}) compared to other landraces (Table 3). Application of 100% RDF + biofertilizers resulted in significantly higher nitrogen (122.0 kg ha^{-1}), phosphorus (36.7 kg ha^{-1}), potassium (141.21 kg ha^{-1}), sulfur (22.4 kg ha^{-1}) and zinc (139.6 g ha^{-1}) uptake as compared to other fertilization levels and biofertilizers. The current study indicated that plant growth, yield and nutrient uptake were positively affected by the application of different fertilization levels and biofertilizers, and their combinations. Similar positive effects of biofertilizer application on rice plant growth and yield were reported in rice [40,43,48,49]; higher uptake depended on genotypic root character of the landraces. The phosphorus uptake was significantly higher in the landrace *Padmarekha* (34.0 kg ha^{-1}), followed by *Hal doddiga* (30.1 kg ha^{-1}) and *Musore sanna* (30.1 kg ha^{-1}). Among the different four fertilization levels, the higher phosphorus uptake with the application of 100% RDF + biofertilizers (36.3 kg ha^{-1}) and 75% RDF + biofertilizers (35.4 kg ha^{-1}) which were on par with each other compared to 50% RDF + biofertilizers (32.4 kg ha^{-1}) and farmer's practice (10.7 kg ha^{-1}). The decrease in phosphorus content under different fertilization levels might be attributed to the consumption of phosphorus, resulting in unstable levels of phosphorus release, and the accessibility of soluble phosphorus in the inoculated culture medium might also have an inhibitory effect on further P solubilization [40,41,53].

Higher S and Zn uptakes were recorded with the landraces *Padmarekha* (18.8 kg ha^{-1} and 114.1 g ha^{-1}) and *Hal doddiga* (18.0 kg ha^{-1} and 111.3 g ha^{-1}). which were on par with each other. The landrace *Mysore sanna* was on par with both genotypes with respect to Zn uptake. Further, the application of 100% RDF + biofertilizers (22.4 kg ha^{-1} and 139.6 g ha^{-1}) recorded significantly higher S and Zn uptake by the crop (Table 3).

Improved nutrient uptake was mainly due to healthier root development, encouraging dry matter production and accumulation, which in turn, helped maximize the yield and productivity of the rice [55]. Nutrient loss with the use of organic nutrient sources and biofertilizers was comparatively lower, and the efficiency of the applied nutrients was higher, resulting in higher nutrient uptake [56]. Thus, it could be concluded that the increased uptake and availability of nutrients came as a result of the synergistic relationship between the biofertilizers and the inorganic sources, similar results as reported by rice researchers [57–59].

The landrace *Padmarekha*, with application of 100% RDF with biofertilizers, recorded greater uptake of nutrients, followed by 75% RDF along with biofertilizers. This genotype performed well during both years of experimentation with different fertility levels, including the farmer's practice. The soil application of zinc 25 kg per ha along with farmyard manure and biofertilizers (common to all treatments except control) promoted better uptake of sulfur [60]. Further, the uptake of phosphorus, potassium, zinc and sulfur was significantly high with biofertilizer-treated and zinc-fertilized plots, except the farmer's practice. Such a synergistic relationship between nitrogen and sulfur was reported in lowland rice [60,61].

Table 3. Uptake of nitrogen (kg ha^{-1}), phosphorus (kg ha^{-1}), potassium (kg ha^{-1}), sulfur (kg ha^{-1}) and zinc (g ha^{-1}) of traditional paddy landraces as influenced by different fertilizer levels in conjunction with biofertilizer practices in the coastal areas of Kumta Taluk, Uttara Kannada district, Karnataka, India.

Varieties	Uptake of N			Uptake of P_2O_5			Uptake of K_2O			Uptake of S			Uptake of Zn		
	2017	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**	**2017**	**2018**	**Pooled**
M_1: *Hal doddiga*	90.0 **	94.2 **	**92.1**	30.3	31.0	**30.6**	101.9	105.5	**103.7**	18.0	17.9 **	**18.0 ****	110.6 **	111.9 **	**111.3 ****
M_2: *Mysore sanna*	79.6	67.1	**81.6**	29.6	30.6	**30.1**	99.1	102.8	**100.9**	17.7	17.6 **	**17.7**	107.8 **	110.1 **	**108.9 ****
M_3: *Padmarekha*	102.8 **	91.6 **	**104.1 ****	33.8 **	34.1 **	**34.0 ****	108.1 **	113.5 **	**110.8 ****	19.0 **	18.6 **	**18.8 ****	112.8 **	115.3 **	**114.1 ****
M_4: *Halga*	88.9 **	84.7	**90.8**	27.6	30.4	**29.0**	94.0	97.3	**95.6**	17.5	17.4	**17.5**	101.8	108.8	**105.3**
M_5: *Kemp jadda bhatta*	92.7 **	94.5 **	**94.5**	26.6	28.8	**27.7**	92.1	95.8	**94.0**	17.1	17.1	**17.1**	101.1	106.8	**104.0**
M_6: *Kari kagga*	54.8	50.5	**56.4**	19.2	19.9	**19.5**	85.1	89.8	**87.5**	15.4	15.3	**15.3**	94.6	96.7	**95.6**
Mean	**84.8**	**80.4**	**86.6**	**27.8**	**29.2**	**28.5**	**96.7**	**100.8**	**98.7**	**17.5**	**17.3**	**17.4**	**104.8**	**108.3**	**106.5**
S.Em±	**1.4**	**1.1**	**2.3**	**0.6**	**0.6**	**0.3**	**1.4**	**1.6**	**0.9**	**2.6**	**0.3**	**0.2**	**2.6**	**1.4**	**1.9**
LSD (*p* = 0.05)	**16.6**	**4.2**	**8.5**	**2.2**	**2.1**	**1.2**	**5.0**	**5.7**	**3.1**	**0.6**	**1.1**	**0.8**	**9.6**	**5.2**	**6.8**
Fertilization levels															
S_1: Farmer's practice	47.1	47.1	**47.1**	9.0	10.7	**9.9**	32.2	35.9	**34.1**	39.9	6.7	**6.8**	39.9	41.7	**40.8**
S_2: 50% RDF + biofertilizers	82.1	85.8	**84.5**	32.1	32.8	**32.4**	96.3	99.9	**98.1**	112.8	19.2	**19.2**	112.8	119.2	**116.0**
S_3: 75% RDF + biofertilizers	96.3	101.3 **	**98.9**	34.3 **	36.4 **	**35.4 ****	120.8	124.4	**122.6**	21.1 **	21.2 **	**21.2**	128.2	131.3	**129.7**
S_4: 100% RDF + biofertilizers	113.7 **	86.6	**122.0 ****	35.9 **	36.7 **	**36.3 ****	137.7 **	142.9 **	**140.3 ****	22.5 **	22.2 **	**22.4 ****	138.3 **	138.3 **	**139.6 ****
Mean	**84.8**	**80.4**	**86.6**	**27.8**	**29.2**	**28.5**	**96.7**	**100.8**	**98.7**	**17.5**	**17.3**	**17.4**	**104.8**	**108.3**	**106.5**
S.Em±	**2.7**	**1.6**	**1.6**	**0.9**	**0.5**	**0.5**	**1.9**	**1.9**	**0.8**	**0.5**	**0.5**	**0.3**	**3.1**	**2.2**	**2.0**
LSD (*p* = 0.05)	**7.9**	**4.5**	**3.8**	**2.5**	**1.4**	**1.3**	**5.4**	**5.4**	**2.3**	**1.5**	**1.3**	**0.9**	**8.9**	**6.2**	**5.7**
Interaction (M × S)															
S.Em±	**5.5**	**3.1**	**2.6**	**1.1**	**0.9**	**0.6**	**1.4**	**1.5**	**0.8**	**1.1**	**0.9**	**0.7**	**6.2**	**4.3**	**4.0**
LSD (*p* = 0.05)	**15.8**	**9.0**	**7.6**	**3.2**	**2.7**	**1.7**	**3.9**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Note: Biofertilizers included *Azospirillum* + *Bacillus megatherium* var. Phosphoticum + *Frateuria quaratia* + *Thiobacillus thiooxidans* + Vesicular Arbuscular Mycorrhiza. Farmer's practice includes only the application of NPK, as mentioned in the methodology, without any biofertilizers; ** refers to significant at p = 0.05. The pooled average mentioned in the table in bold numbers.

Supplying the recommended doses of nutrients in conjunction with different nutrient solubilizers in the form of biofertilizers had good compatibility in dissolving complex nutrient ions to simpler forms, permitting the easy availability of nutrients to the crop plants [41,43]. The higher nutrient uptake with chemical fertilizer+ bioinoculant-treated plants might be due to augmentation of the biological N_2 fixation and/or the synthesis of organic acids, which could help in P, K, S and Zn solubilization. Furhter, the purpose of all mycorrhizal systems (VAM) hangs on the ability of the fungal symbiont to acquire the inorganic and/or organic nutrient ions available in the soil [23] when it is supplied through plant root inoculation.

The increase in the uptake of nutrients by paddy crops with the application of RDF and biofertilizers signifies the role of inoculants in releasing nutrients to the rhizosphere and making them available to plants. Bioinoculants, in combination with the existing microorganisms in the native soils of the experiment site, would have increased root and shoot growth and, in turn, the acquisition of nutrient ions in the plant rhizosphere of the crop [41,60,61]. The nutrients N and P's application rates had the maximum contributions to increases in Zn uptake, and this could be due to their higher contributions to biological yield rather than rest factors [60,62]. The application of 25 kg zinc sulfate per ha as a common dose would be sufficient to be made available for crop uptake in sufficient quantities. Under such circumstances, the ability for plant nutrient uptake (dry matter production) would decide the Zn uptake, which would have the combined influence of NPK applications contributing to its growth [46,63]. Other factors such as hydrologic regimes in soils and variations in crop vigor and yield of the crops also add to increased uptake of nutrients.

The soil fertility status after crop harvest reflected the nutrients' dynamics of nutrient application, uptake and loss. Significantly higher available P_2O_5 and K_2O content of the soil was observed in the plots grown with *Padmarekha* (24.9 and 202.3 kg ha^{-1}). The N content did not differ significantly with any of the landraces. The sulfur content was on par with four landraces, except *Kempajadda Bhatta* and *Karikagga*, and higher Zn content was recorded in the plots grown with *Padmarekha* (12.2 ppm). Among the subplots with different fertilization levels, 100% RDF + biofertilizers recorded significantly higher N, P_2O_5, K_2O, S and Zn content (209.2, 32, 204.7 kg ha^{-1} and 20.4 and 14.9 ppm, respectively) (Table 4).

The application of biofertilizers like *Azospirillum* with 100% fertilization levels might have contributed to increases in nitrogen content in the soil [43,48]. The *Bacillus megatherium* var. Phosphoticum contributed to solubilizing the native P sources in the soil reflected higher available phosphorus [2,40] after harvest of rice. *Frateuria quaratia* might have been instrumental in replenishing the K content in the post-harvest soils. Similar results were observed in tobacco crop [64]. The inoculants with *Thiobacillus thiooxidans* helped to oxidize the sulfur present in the soil and thus increased the sulfur content in post-harvest soils [65]. VAM might have helped to increase the availability of phosphates in the post-harvest soil in addition to offering disease resistance to the crop and survival in unfavorable weather conditions [66,67].

Thus, use of biofertilizers deserves priority for the sustained production and higher resource utilization efficiency in integrated nutrient management, i.e., the use of biofertilizers with organic and/or inorganic fertilizers for increasing yield traditional paddy landraces. Thus, the present study confirms that maximization of the yields of traditional paddy landraces could be possible using bioinoculants along with chemical fertilizers besides improving nutrient uptake and utilization of the applied nutrients in the coastal region of Karnataka.

Table 4. Available N, P_2O_5, K_2O (kg ha^{-1}) S and Zn (ppm) after harvest of traditional paddy landraces, as influenced by different fertilizer levels in conjunction with biofertilizer practices in the coastal areas of Kumta Taluk, Uttara Kannada district, Karnataka, India.

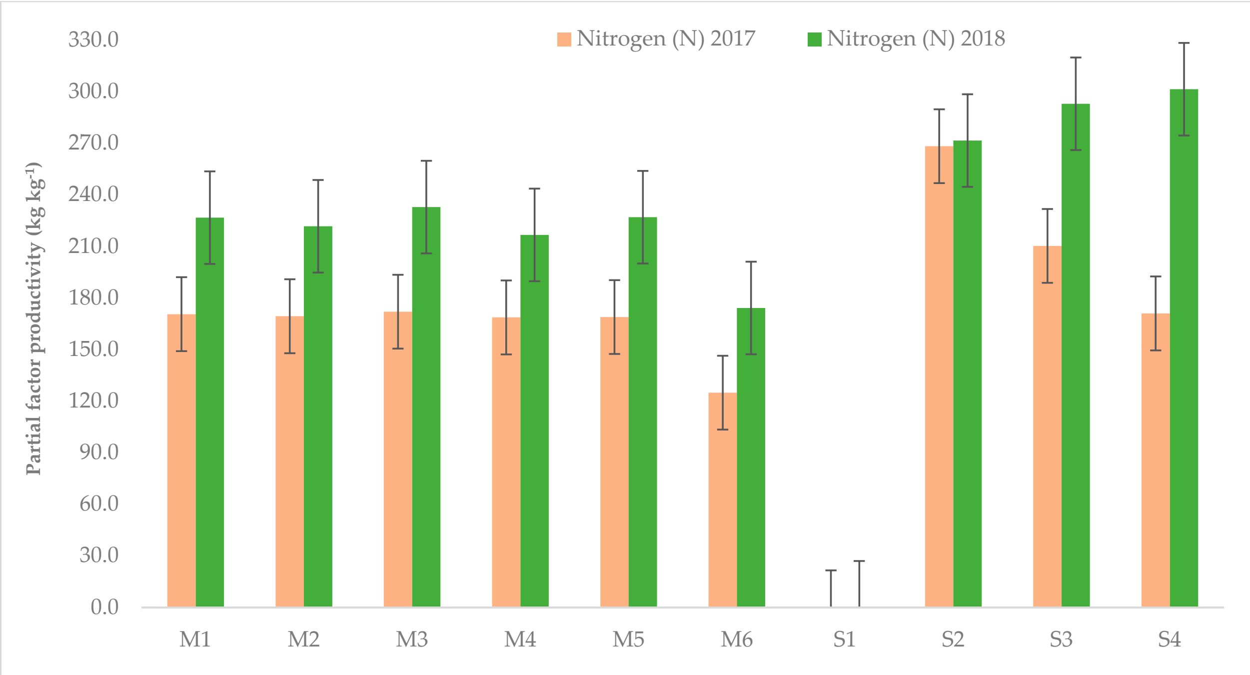
Varieties	Available N			Available P_2O_5			Available K_2O			Available S			Available Zn		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
M_1: *Hal doddiga*	182.5	192.3	**187.4**	22.1	23.2	**22.6**	196.0	196.7	**196.4**	15.9 **	17.1 **	**16.5 ****	10.5 **	13.0 **	**11.7**
M_2: *Mysore sanna*	186.3	194.0	**190.1**	23.2 **	23.5	**23.4 ****	197.9	198.6	**198.2**	15.9 **	17.0 **	**16.4 ****	10.3	12.9	**11.6**
M_3: *Padmarekha*	187.7	195.3	**191.5**	24.4 **	25.4 **	**24.9 ****	201.9 **	202.6 **	**202.3 ****	16.3 **	17.4 **	**16.9 ****	10.9 **	13.4 **	**12.2 ****
M_4: *Halga*	185.7	194.3	**190.0**	23.9 **	24.9 **	**24.4 ****	198.8	199.6	**199.2**	15.6 **	16.7	**16.2 ****	10.3	12.7	**11.5**
M_5: *Kemp jadda bhatta*	182.8	195.2	**189.0**	21.6	22.3	**22.0**	199.7	200.4	**200.0**	15.3 **	16.2	**15.7**	10.2	12.5	**11.3**
M_6: *Kari kagga*	177.6	186.1	**181.9**	20.4	20.5	**20.4**	192.4	193.2	**192.8**	13.6	14.1	**13.9**	9.5	11.6	**10.5**
Mean	**183.8**	**192.9**	**188.3**	**22.6**	**23.3**	**23.0**	**197.8**	**198.5**	**198.2**	**15.4**	**16.4**	**15.9**	**10.3**	**12.7**	**11.5**
S.Em±	**2.85**	**2.07**	**1.78**	**0.41**	**0.3**	**0.3**	**0.04**	**0.05**	**0.03**	**0.37**	**0.38**	**0.26**	**0.14**	**0.25**	**0.11**
LSD (p = 0.05)	**NS**	**NS**	**NS**	**1.51**	**1.08**	**1.1**	**0.16**	**0.18**	**0.11**	**1.33**	**1.38**	**0.93**	**0.52**	**0.89**	**0.40**
Fertilization levels															
S_1: Farmer's practice	164.9	173.9	**169.4**	14.2	15.2	**14.7**	191.0	191.8	**191.4**	6.6	7.2	**6.9**	4.2	5.1	**4.7**
S_2: 50% RDF + biofertilizers	172.5	180.3	**176.4**	19.6	20.7	**20.1**	195.4	196.2	**195.8**	16.7	18.0	**17.4**	11.3	13.9	**12.6**
S_3: 75% RDF + biofertilizers	193.4	203.2	**198.3**	24.8	25.2	**25.0**	200.3	201.1	**200.7**	18.6	19.4	**19.0**	12.2	15.2	**13.7**
S_4: 100% RDF + biofertilizers	204.2 **	214.1 **	**209.2 ****	31.8 **	32.1 **	**32.0 ****	204.3 **	205.1 **	**204.7 ****	19.8 **	21.0 **	**20.4 ****	13.4 **	16.5 **	**14.9 ****
Mean	183.8	192.9	**188.3**	22.6	23.3	**23.0**	197.8	198.5	**198.2**	15.4	16.4	**15.9**	10.3	12.7	**11.5**
S.Em±	**2.81**	**3.34**	**1.89**	**0.94**	**0.38**	**0.51**	**0.03**	**0.03**	**0.02**	**0.52**	**0.39**	**0.26**	**0.20**	**0.27**	**0.20**
LSD (p = 0.05)	**8.12**	**9.64**	**5.46**	**2.7**	**1.08**	**1.46**	**0.11**	**0.10**	**0.07**	**1.50**	**1.12**	**0.72**	**0.57**	**0.79**	**0.57**
Interaction (M × S)															
S.Em±	**1.93**	**1.52**	**1.2**	**1.01**	**0.59**	**0.65**	**0.03**	**0.03**	**0.02**	**1.04**	**0.77**	**0.50**	**0.40**	**0.55**	**0.40**
LSD (p = 0.05)	**NS**	**NS**	**NS**	**NS**	**1.7**	**1.88**	**0.08**	**0.09**	**0.05**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Note: Biofertilizers included *Azospirillum* + *Bacillus megatherium* var. Phosphoticum + Frateuria quaratia + *Thiobacillus thiooxidans* + Vesicular Arbuscular Mycorrhiza. Farmer's practice includes only the application of NPK, as mentioned in the methodology, without any biofertilizers. ** refers to significant at p = 0.05. The pooled average mentioned in the table in bold numbers.

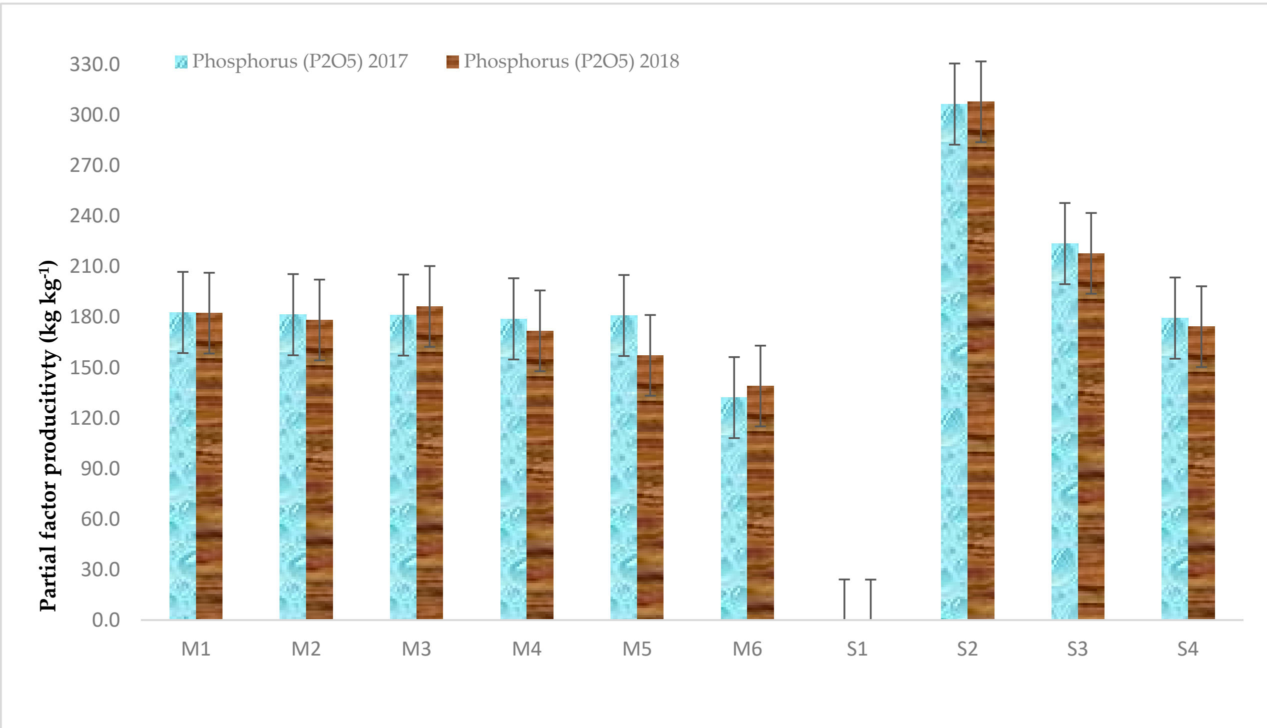
Higher partial factor productivity (PFP) with respect to N, P_2O_5 and K_2O was recorded with the genotype *Padmarekha*, with the application of 50% RDF + biofertilizers (biofertilizers included *Azospirillum* + *Bacillus megatherium* var. Phosphonium + *Frateuria quaratia* + *Thiobacillus thiooxidans* +VAM) (Figure 1). The addition of organic sources such as manures and biofertilizers will be helpful to curtail the addition of chemical fertilizers. The higher PFP could be due to higher yields with the same levels of NPKSZn fertilization, microbial consortia and organic manure application in different treatments. Among nutrient management practices, the significantly higher PFP observed with 50% RDF + biofertilizers were due to lower nutrient application rates with the sustainable yields obtained in those treatments. Thus, the contribution of microbial inoculants in terms of increasing PFP of N, P_2O_5 and K_2O, is most important to enhance the efficiency of the applied nutrients for a staple crop with higher nutrient demand. The yield increase per kg of nutrient added helped in reducing further nutrient additions to the crops [68], which could be helpful in reducing pollution problems. The PFP of the other landraces, i.e., *Hal Doddiga*, *Mysore Sanna*, *Halga* and *Kemp Jadda Bhatta* were on par with each other except for the landrace *Karikagga*, which recorded the lowest PFP. This inferred that the landraces were equally effective in utilizing the applied nutrients.

In the present investigation, the application of the full recommended dose of inorganic fertilizer produced the highest yield attributes [69] compared to the farmer's practice. Satisfying the requirement of nutrients by the crop, the combined application of organic manure, inorganic fertilizer and biofertilizers was found equally capable of supplying nutrient elements in available forms due to their rapid release from chemical sources and slow and steady release from biofertilizers in the soil along with essential micronutrients and growth-promoting substances, which resulted in higher growth and yields of crops. In view of the deleterious effects of chemical fertilizer application, entire production systems in the present day are looking toward alternative sources such as biofertilizers to be supplements to sustaining productivity [46,68]. Adopting the FYM incorporation, integrated nutrient management strategies would certainly increase soil organic carbon, further promoting the sustainability of rice-based production systems [69–71].

Local landraces are slowly being ignored which are being replaced by hybrids/ high yielding varieties to promote higher yields in crops like rice. However, there is better scope for increasing the most potential local landraces such as *Padmarekha*, which is well adopted in coastal areas and preferred due to its unique taste, aroma and cooking quality besides showing resistance to the major disease like blast [26]. Thus, our present investigation with the adoption of integrated nutrient management practices such as the inclusion of organic manures, chemical fertilizers and bioinoculants would be helpful in not only improving the yields, but also preserving the elite landraces of paddies in the coastal areas, in addition to improving soil fertility. This current investigation would also help in preserving the local landraces of paddies which have been in cultivation since ancient ages. However, these have been ignored in the recent past due to their productivity constraints. Thus, this approach of inoculating bio-fertilizers to crops besides applying chemical fertilizers and organic manures could help in sustaining the yield levels of unique landraces attract rice growers.

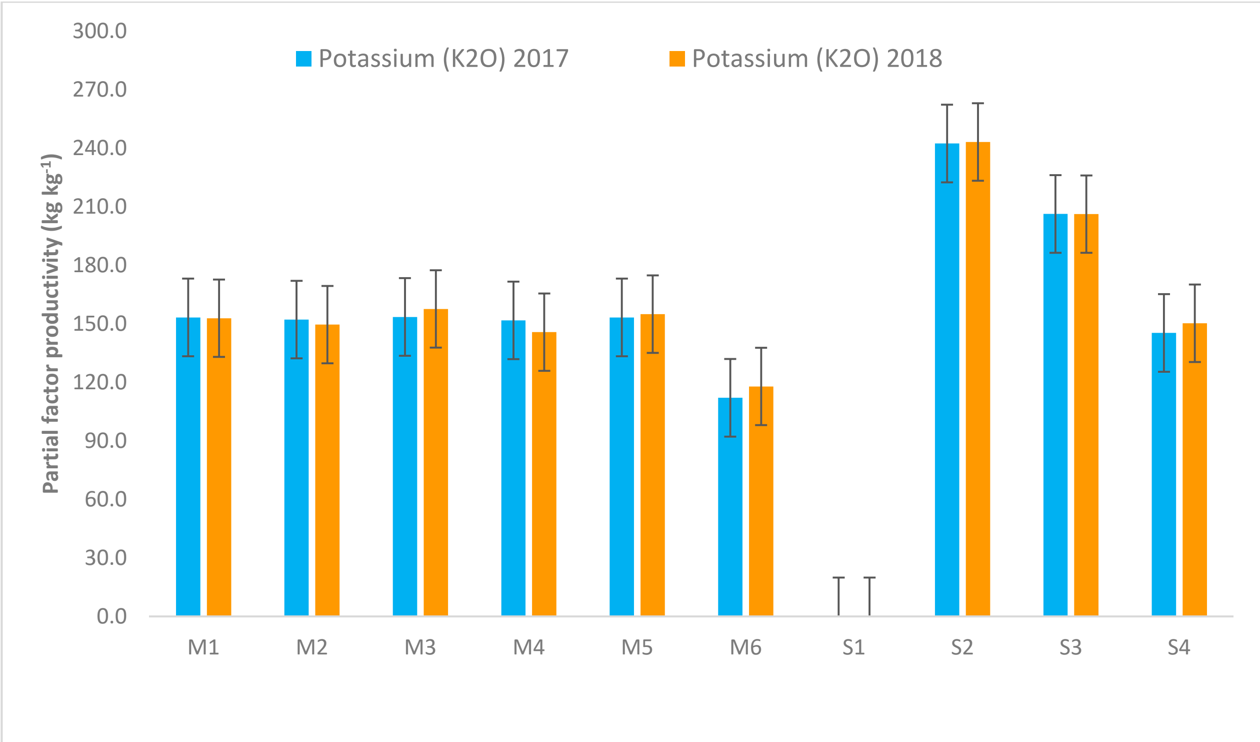


(A) Nitrogen



(B) Phosphorus

Figure 1. *Cont*.



(**C**) **Potassium**

Figure 1. The partial factor productivity of the paddy landraces, as influenced by different fertility levels in conjunction with biofertilizers during 2017 and 2018. M: Landraces; M_1: Hal doddiga; M_2: Mysore sanna; M_3: Padmarekha; M_4: Halga; Kemp jadda Bhatta; M_6: Kari kagga; **S: Fertility levels; S1: Farmers practice**; S_2: 50 % RDF + biofertilizers; S_3: 75 % RDF + biofertilizers; S_4: 100 % RDF + biofertilizers; S_4: 100 % RDF + biofertilizers; M × S: Interaction; Em: Standard Error of Mean; LSD: Least Significant Difference; Biofertilizers include Azospirillum + *Bacillus megatherium* var. Phosphoticum + *Frateuria quaratia* + *Thiobacillus thiooxidans* +Vesicular Arbuscular Mycorrhiza; Farmers Practice include only application of NPK as mentioned in methodology without any biofertilizers; 4. S1 is the considered as control for different fertilization levels. Vertical bar indicates LSD at $p = 0.05$.

4. Conclusions

The present study reveals that the productivity of traditional paddy landraces could be improved using the 100% recommended dose of fertilizers (75:75:90 NPK Kg ha^{-1}) in combination with *Azospirillum* + *Bacillus megatherium* var. Phosphoticum + *Frateuria quaratia* + *Thiobacillus thiooxidans* + Vesicular Arbuscular Mycorrhiza. The effectiveness of the nutrient management could be further improved by adding 5 tons of FYM, 25 kg of $ZnSO_4$ and 500 kg lime per ha (which was applied to all the treatments except farmer's practice) under the acidic soils of coastal areas, in terms of growth and yield attributes in local landraces such as *Padmarekha*. Further, this would be helpful in preserving the fertility of soils in addition to improving the sustainability of the rice production system. The taller plants, higher number of tillers per hill, dry matter accumulation, number of grains per panicle, grain weight per spike, test weights, grain and straw yields were higher with the variety *Padmarekha* besides increased nutrient uptake (NPKSZn) and partial factor productivity.

The inoculation of biofertilizers + 100% RDF resulted in enhancing grain and straw yield, which was the impact of increases in growth and yield attributes. Higher nutrient uptake was observed, predicting the higher partial factor productivity of applied nutrients with the same treatment. However, our results with the biofertilizer inoculation had the best impacts on increasing productivity. Further, it was also observed that the partial factor productivity was higher upon reduction of the fertilizer application. Thus, the current research revealed that integration of biofertilizer inoculation with 100% inorganic fertilization would serve as an effective tool for rice growers for improving productivity of local paddy landraces.

Author Contributions: Conceptualization, T.H.N., R.N.; methodology, T.H.N., R.N., S.K.S.; software, T.H.N., S.K.S., K.V.R., H.O.E.; validation, T.H.N., S.K.S., H.O.E.; formal analysis, T.H.N., S.K.S., K.V.R.; investigation, T.H.N., R.N.; resources, T.H.N., R.N.; data curation, T.H.N., H.O.E., F.F.A.-H., T.K.Z.E.-A.; writing—original draft preparation, S.K.S., T.H.N.; writing—review and editing, T.H.N., K.V.R., A.M.M.A., S.A.M.A., F.F.A.-H.; visualization, T.H.N., R.N.; supervision, T.H.N., R.N.; project administration, T.H.N., H.O.E.; funding acquisition, H.O.E., A.M.M.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Deanship of Scientific Research at Princess Nourah bint Abdulrahman University through the Fast-Track Research Funding Program. We also would like to thank Kuvempu University for institutional and infrastructure facilities provided during the course of study.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data are available in this paper.

Conflicts of Interest: The authors declare no conflict of interest.

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