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The Uptake of Phosphorous and Potassium of Rice as Affected by Different Water and Organic Manure Management

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Abstract: The effects of two water regimes *viz*. continuous ponding (CP) and intermittent ponding (IP) along with three organic amendments such as cow manure (CM), poultry manure (PM) and rice husk (RH) on growth and yield of rice (*Oryza sativa* L.) was studied in this work. Rice was grown in pots having sandy loam soils in the Department of Soil Science, University of Chittagong, Bangladesh. Organic amendments generally improved yield and concentration as well as accumulation of phosphorus and potassium under both CP and IP conditions. The dry weight of grain and straw did not differ significantly among the organic amendments. The concentration and accumulation of phosphorus in different parts of rice plants was found higher in CP condition in comparison to IP under all organic amendments. However, the uptake of potassium was higher under IP condition in general, and the maximum concentration and accumulation was found when poultry manure was incorporated with soil under IP condition. Total accumulation of phosphorus followed the order of grain>shoot>root, and the sequence of potassium accumulation was found as shoot>grain>root. The results of the present experiment indicated that intermittent irrigation with organic amendments especially poultry manure could be one of the best approaches for maintaining better yield of rice and uptake of potassium with application of minimum irrigation water.

Keywords: Continuous Ponding, Cow Manure, Intermittent Ponding, Poultry Manure

1. Introduction

Rice (*Oryza sativa* L.) is the most important cereal crop in Bangladesh which contributes to 91% of total cereal consumption per capita and also greatly provide human as well as animal nutrition [1]. Flooded irrigation, which requires large amounts of water, is the dominant water management practice in rice production systems and may also be responsible for greenhouse gas emission. In addition, low nutrient-use efficiencies due to high losses in flooded rice culture system result in contamination of groundwater and high demand and ultimately cost of fertilizers for farmers [2]. On the other hand, many climate models forecast that much of the agricultural land across the world will experience increasing dryness and more variable rainfall patterns with longer periods without or with little rain [3-4]. Because of water scarcity which mostly occurs in the dry season (November to April), aerobic water management of rice production is practiced in small scale in Bangladesh which requires less water compared to conventional flood irrigation [5]. Soil moisture plays an important role in the mineralization of organic amendments [6] and affect plant growth and agricultural production [7]. However, plant growth, yield and nutrient supply through mineralization depend on the severity and duration of water stress [8]. Decrease in soil moisture influences the rate of diffusion and mass flow of plant nutrients in soil [9-12] ultimately affecting plant uptake of nutrients through reduced root growth and by changing root uptake capacity [13].

Attaining maximum yield through the incorporation of different organic manures with minimum application of irrigation water could be the best management practices for rice cultivation. The application of organic matter improves the quality of soil physically, chemically and biologically. In addition to decreasing water requirement, application of low C:N organic matter especially poultry manure alone or in combination to chemical fertilizers is practiced for wetland rice cultivation in many rice growing areas of Asia because of high cost of chemical fertilizers and quick loss of nutrients from added fertilizers which ultimately cause environmental pollution mostly surface and ground water pollution [14-17].

Although the effects of variable water regimes on plant growth and uptake of some nutrients have been examined in many experiments, very few is known about the effects of water regimes on plant growth, yield and uptake of nutrients especially phosphorus and potassium under different organic amendments. Thus, the objective of this study was to reveal the effects of soil moisture regimes on growth, yield and uptake of phosphorus and potassium in rice as affected by different organic amendments.

2. Materials and Methods

2.1. Collection and Processing of Soil and Organic Amendments

Bulk soil samples from a depth of 0–15 cm were collected from the research field of the Department of Soil Science, University of Chittagong which belongs to Pahartoli soil series of the USDA soil classification system. Collected soils were dried in air, and after removing undesired roots passed through a 5 mm sieve. A portion of soil samples passing through 5 mm sieve was further screened through a 2 mm sieve for analysis of various physical and chemical parameters. Cow manures and poultry manures were collected from local farms and rice husk was collected from a saw mill. After air drying, these materials were sieved through a 0.2 mm sieve and stored to mix with pot soils at specified rates and to analyze for several chemical properties.

2.2. Experimental Setup

A pot experiment involving treatments of a factorial combination of two water regimes and three organic amendments was carried out in the net house of Soil Science Department of Chittagong University in 2014 to observe their effects on the growth and yield of rice (*Oryza sativa* L.). Plastic pots (30 cm height and 25 cm diameter) were filled with 10 kg air dried soil amended with manures such as cow manure (CM,) poultry manure (PM) and rice husk (RH) at the rate of 10 t ha^{-1} and inorganic fertilizers at the rate of 224 kg ha^{-1} nitrogen, 60 kg ha^{-1} phosphorus and 150 kg ha^{-1} potassium in the form of urea, triple super phosphate and muriate of potash. Manures were well incorporated 15 days before transplanting. There were 8 treatments including a control (without any manure) with three replications. The pots were arranged according to completely randomized design. One third of nitrogen and the whole amount of phosphorus and potassium were applied before transplantation of seedlings. After 15 days of applying treatments, six 35 days old rice seedlings (Eratom- a rice variety released by Bangladesh Institute of Nuclear Agriculture, BINA) were transplanted. The seedlings were grown in two water regimes *viz*. continuous ponding (CP), where a constant depth of 2-3 cm water was maintained during the growing season, and intermittent ponding (IP), where irrigation was applied 3-4 days after disappearance of excess water in the surface from 15 days of transplantation under three organic sources *viz.* cow manure (CM), poultry manure (PM) and rice husk (RH), and control having no organic manure. The remaining nitrogen was applied in two installments, one at panicle initiation stage and the other at flowering stage. Plants were thinned to four seedlings after 15 days of transplantation, and weeding was done whenever necessary. A pesticide named Fyfanon (chemical name- Malathion 57 EC) was sprayed at panicle initiation stage and grain development stage of plants.

2.3. Collection and Processing of Plant Samples

Plants were harvested manually from each pot after 80 days of transplantation. Grains were collected two days before, and roots were collected two days after harvest of shoot. The shoots were cut at the root-shoot joint usually from 2 cm above the surface. After collection, the roots were washed first with tap water, then several times with distilled water to remove any soil particle adhering to the root. Height of shoots, number of panicles, fresh and oven dry weight of shoots and grains, thousand grain weights and weight of unfilled grains were recorded. Then the samples were dried in oven at 70±5°C for four days for complete removal of moisture. Oven-dried plant samples were ground and passed through 0.2 mm sieve for analyses of phosphorus and potassium.

2.4. Methods of Analysis

Soil pH was measured by a Mettler Toledo pH meter after preparing the suspension at a ratio of 1:2.5 (soil:water). Soil organic carbon content was determined by Walkley and Black wet-oxidation method [18]. For the determination of ammonium-nitrogen (NH_4^+-N), the soil samples were extracted with 1N potassium chloride solution at a ratio of 1:10. Then, Ten ml extract was distilled with 10 ml of 40% sodium hydroxide solution using a micro Kjeldahl distilling unit into an Erlenmeyer flask containing 10 ml boric acid- mixed indicator solution until about 60 ml distillate in each flask was collected. After distillation, ammonium content was determined in the distillate by titrating with standardized (0.014 N) sulphuric acid. Exchangeable potassium in soil was determined after extracting the soil with 1N ammonium acetate at pH 7 at a ratio of 1:10 [19]. For the determination of total nitrogen, phosphorus, potassium, calcium and magnesium of soil and organic manures, the samples were digested with a digestion mixture prepared by mixing 350 ml H_20_2, 0.42 g Se powder, 14 g $LiSO_4$. H_20 and 420 ml concentrated H_2SO_4 [20]. The digestion of a suitable amount of soil (1.0 g) and manure samples (0.5 g) was performed with 6 ml digestion mixture solution in a digestion block by heating with a starting temperature of 50°C that was increased progressively to 350°C [21]. The total phosphorus was determined colorimetrically using a spectrophotometer at a wavelength of 490 nm by developing yellow color with vanadomolybdate. The available phosphorus of the soil was determined calorimetrically by ascorbic acid blue color method [22] after extracting the soil samples by using the Bray and Kurtz- 1 solution. The available and total potassium in soil and manure samples were determined by atomic absorption spectrometer. Exchangeable and total calcium and magnesium were determined by Ethylene Di-amine Tetra Acetic Acid (EDTA) method as described in Huq and Alam [23].

2.5. Statistical Analysis

Duncan's Multiple Range Test was performed to indicate significance of differences between any two treatments. Microsoft Excel (2003 and 2007) and SPSS-16 software packages were used for the preparation of figures and analysis of variance for the significance of treatment effects.

3. Results

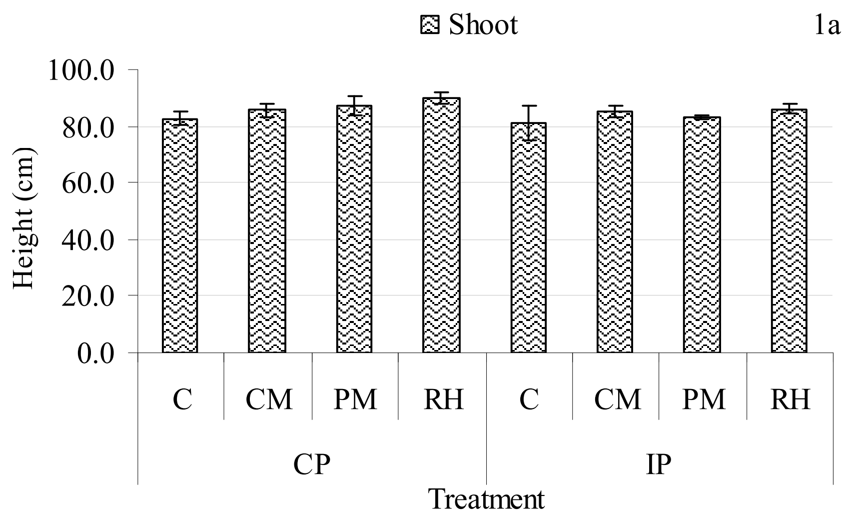
The experimental soil was sandy loam in texture containing 64% sand, 23% silt and 14% clay. Some physical and chemical properties of soil and organic amendments used for the present work are shown in Table 1.

Table 1. *Physico-chemical characteristics of soil and organic sources.*

Parameter	Cow manure	Poultry manure	Rice husk	Soil
pH	7.65	6.73	7.23	5.47
Organic carbon (%)	10.09	15.32	14.48	0.43
Total nitrogen (%)	1.08	2.39	0.90	0.16
Total phosphorus (%)	0.73	1.60	0.70	0.05
Total potassium (%)	0.71	1.63	0.47	0.42
Total calcium (%)	0.73	2.47	0.67	0.27
Total magnesium (%)	1.36	2.16	0.56	0.48
NH_4^+-N (mg kg^{-1})	-	-	-	66.73
Available phosphorus (mg kg^{-1})	-	-	-	27.00
Exchangeable potassium (mg kg^{-1})	-	-	-	31.20

3.1. Plant Growth and Yield

Figures 1 (a-d) shows the effects of different water regimes and organic manures on yield parameters of rice at harvesting stage. Height, fresh and oven dry weight of shoot and grain were higher in organic amended soils compared to control under both CP and IP conditions. The minimum height of 81 cm was found in control of IP, and the maximum of 89.7 cm was recorded in RH treated soils of CP condition. Continuous ponding gave higher fresh weight of shoot and grain. The application of PM resulted in the highest grain yield per pot (27.89 g), and no addition of manures resulted in the lowest yield (17.96 g) under IP condition. Though fresh weight of shoot of all treatments was high under CP condition, the dry mass was found under IP condition except CM treated soils. The dry weight of root was higher under CP condition and differed significantly ($p<0.05$) from IP condition. However, no significant difference was found in fresh weight of shoot and grain among organic treated soils under CP and IP conditions. The oven dry weight of grain and shoot (except RH treated soils) also did not differ significantly among the organic amendments. In contrast to fresh weight, the panicle number and unfilled grain was higher under IP condition in case of all treatments. Under both CP and IP conditions, maximum fresh weights (139.37 and 127.03 g pot^{-1} respectively) were observed in CM treated soils and minimum in control (103.91 and 121.85 g pot^{-1} respectively). There was no significant difference in thousand-grain weight among all treatments under both water management systems.



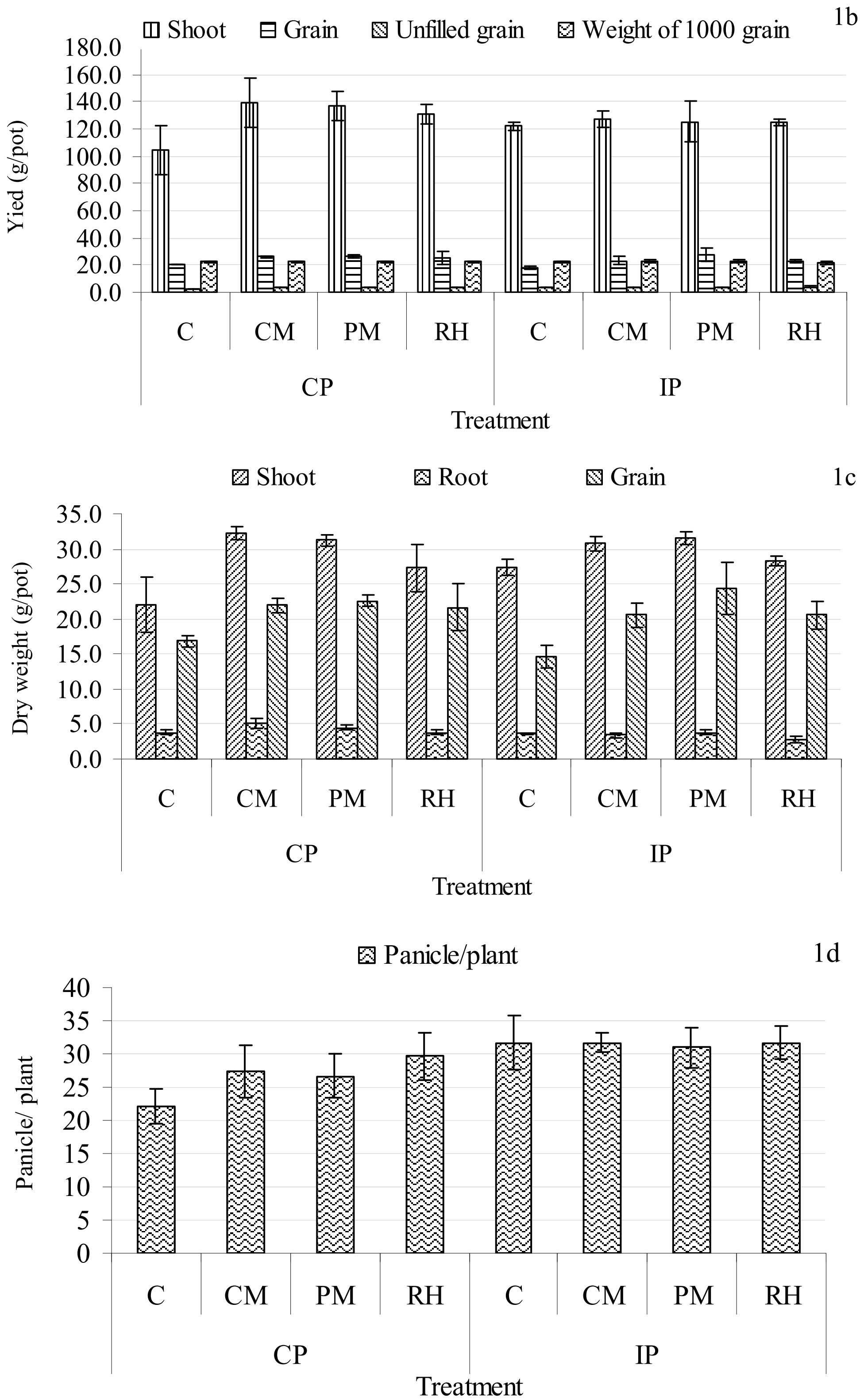
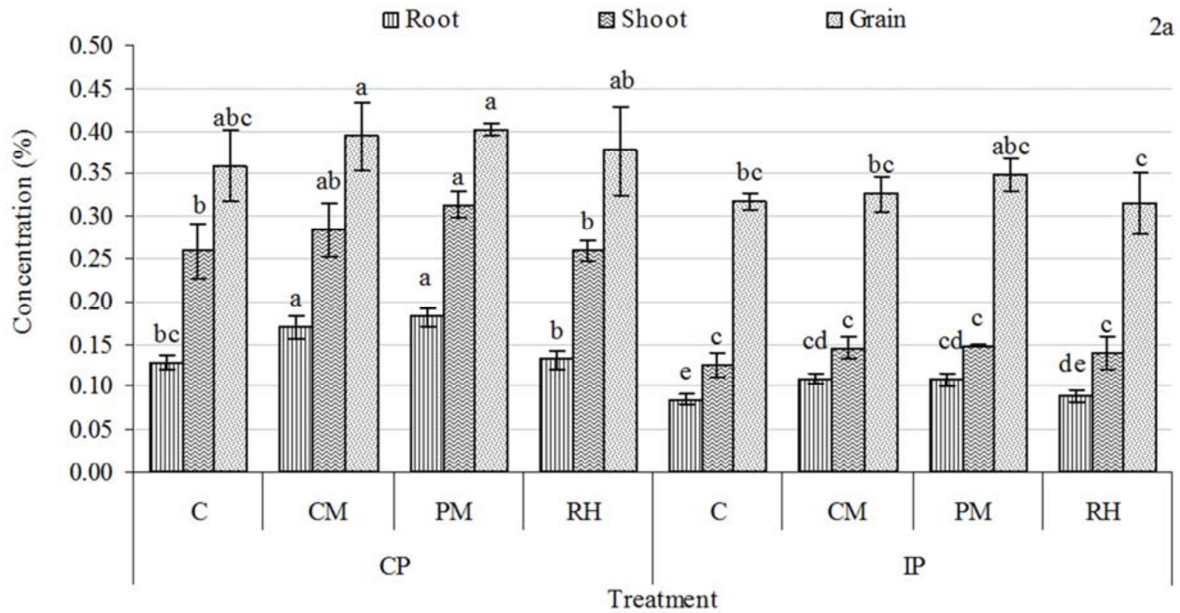


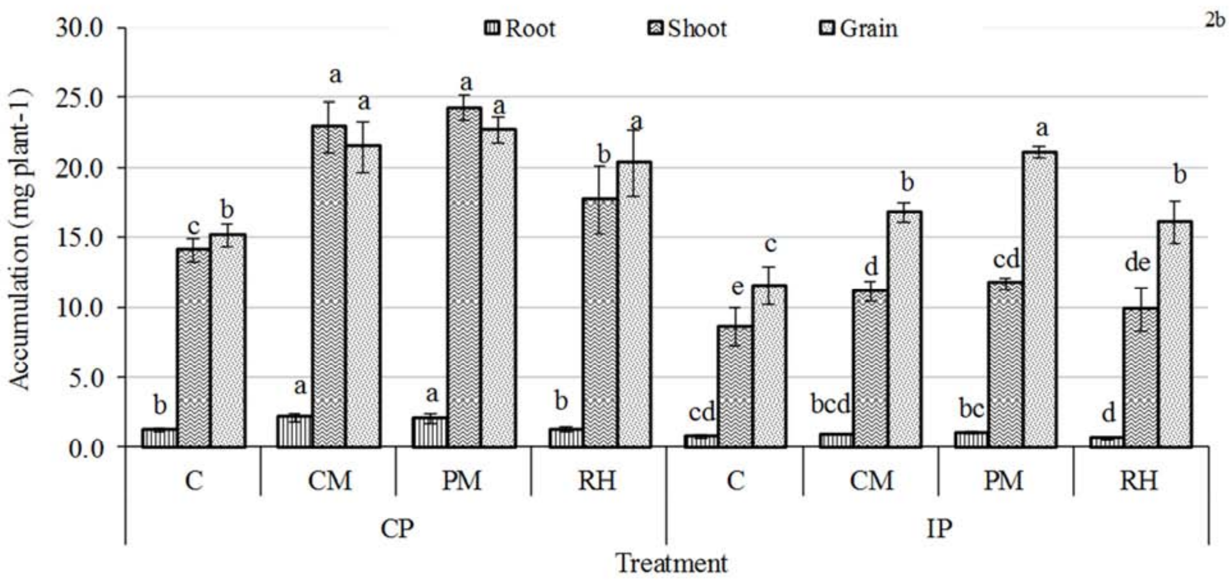
Figure 1. *(a-d) Effect of water regimes and organic manures on yield of rice.*

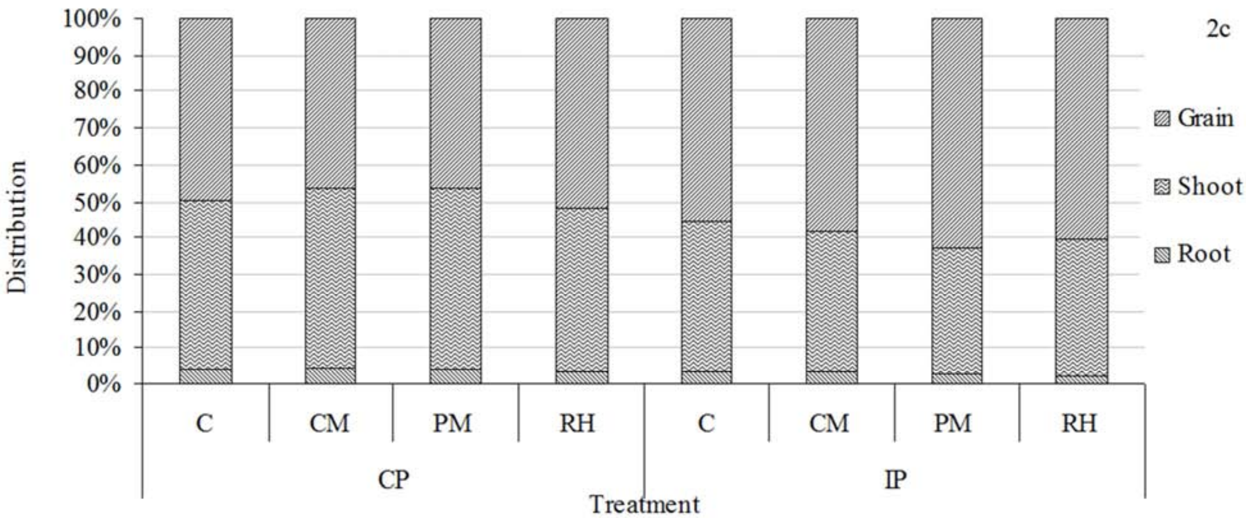
3.2. Concentration, Accumulation and Distribution of Phosphorus in Rice Plants

Figure 2a shows the concentration of phosphorus in different parts of rice plants. The concentration of phosphorus in root, shoot and grain of rice plants grown under CP condition was found higher compared to IP condition. Plants grown in soils amended with organic manures especially with CM and PM responded better in comparison to non-amended soils. The CM and PM resulted in 32 and 42% more phosphorus concentration in root, 10 and 21% higher in shoot and 10 and 12% higher in grain compared to control under CP condition. In case of IP condition, the values were 28 and 29%, 15 and 18%, 3 and 10% respectively for root, shoot and grain. The concentration of phosphorus ranged from 0.13 to 0.18% in root, 0.26 to 0.31% in shoot and 0.36 to 0.40% in grain in CP condition, whereas it ranged from 0.08 to 0.11% in root, 0.13 to 0.15% in shoot and 0.31 to 0.35% in grain in IP condition. However in both CP and IP conditions, the total concentration followed the order: chicken manure> cow manure> rice husk> control. The content of phosphorus in all parts of rice plants significantly ($P<0.05$) varied among different treatments.

Similar to concentration, the accumulation of phosphorus was higher under CP condition compared to IP condition in all parts of plants (Figure 2b). In root and shoot, the accumulation of phosphorus under CP condition was almost double for respective treatments compared to IP condition. The accumulation in root ranged from 0.63 mg plant^{-1} in RH treated soils under IP condition to 2.14 mg plant^{-1} in CM treated soils under CP condition. In shoot and grain, maximum phosphorus (24.27 and 22.66 mg plant^{-1} respectively) accumulated in PM treated soils followed by CM treated soils (22.88 and 21.04 mg plant^{-1} respectively). In shoot and grain, lowest accumulations of 8.59 and 11.53 mg phosphorus per plant were observed in control under IP condition. The total accumulation was found in the sequence of PM>CM>RH>C. Figure 2c shows the distribution of phosphorus accumulated in different parts of rice plants. The distribution was observed in order of grain>shoot>root. In root, the range of distribution of phosphorus was 2.39 to 4.16% with an average value of 3.52% and in shoot, it ranged from 34.57 to 49.55% with an average of 42.67%. In grain, the range of phosphorus accumulation was between 46.19% and 62.43% with an average of 53.81%.





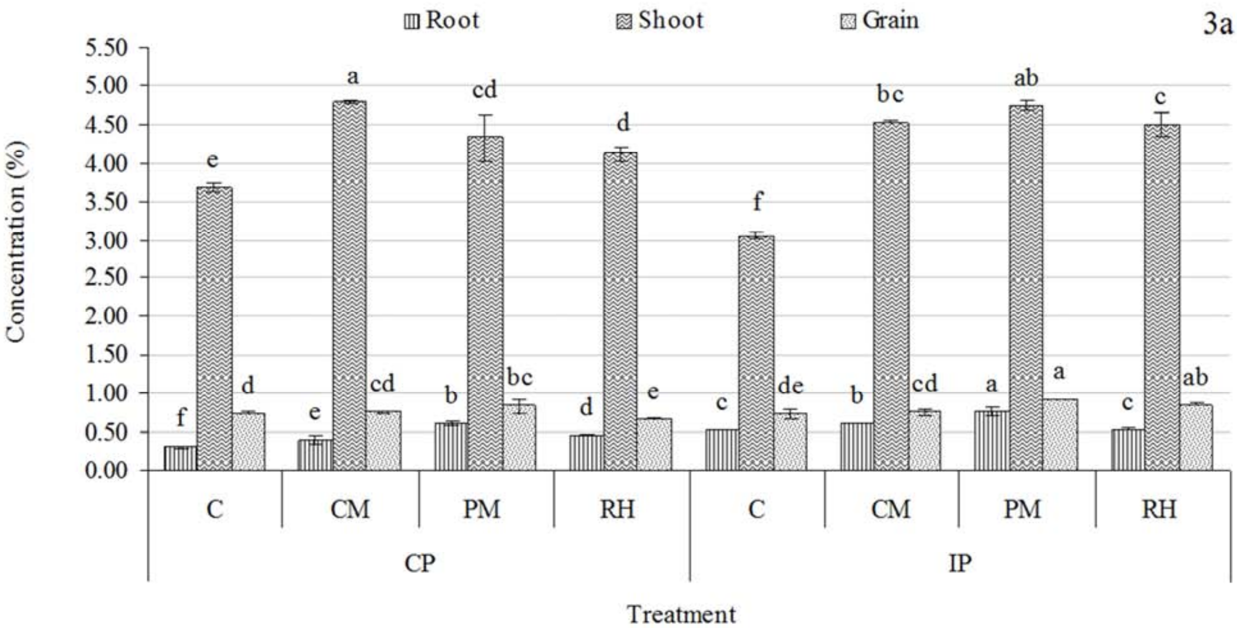


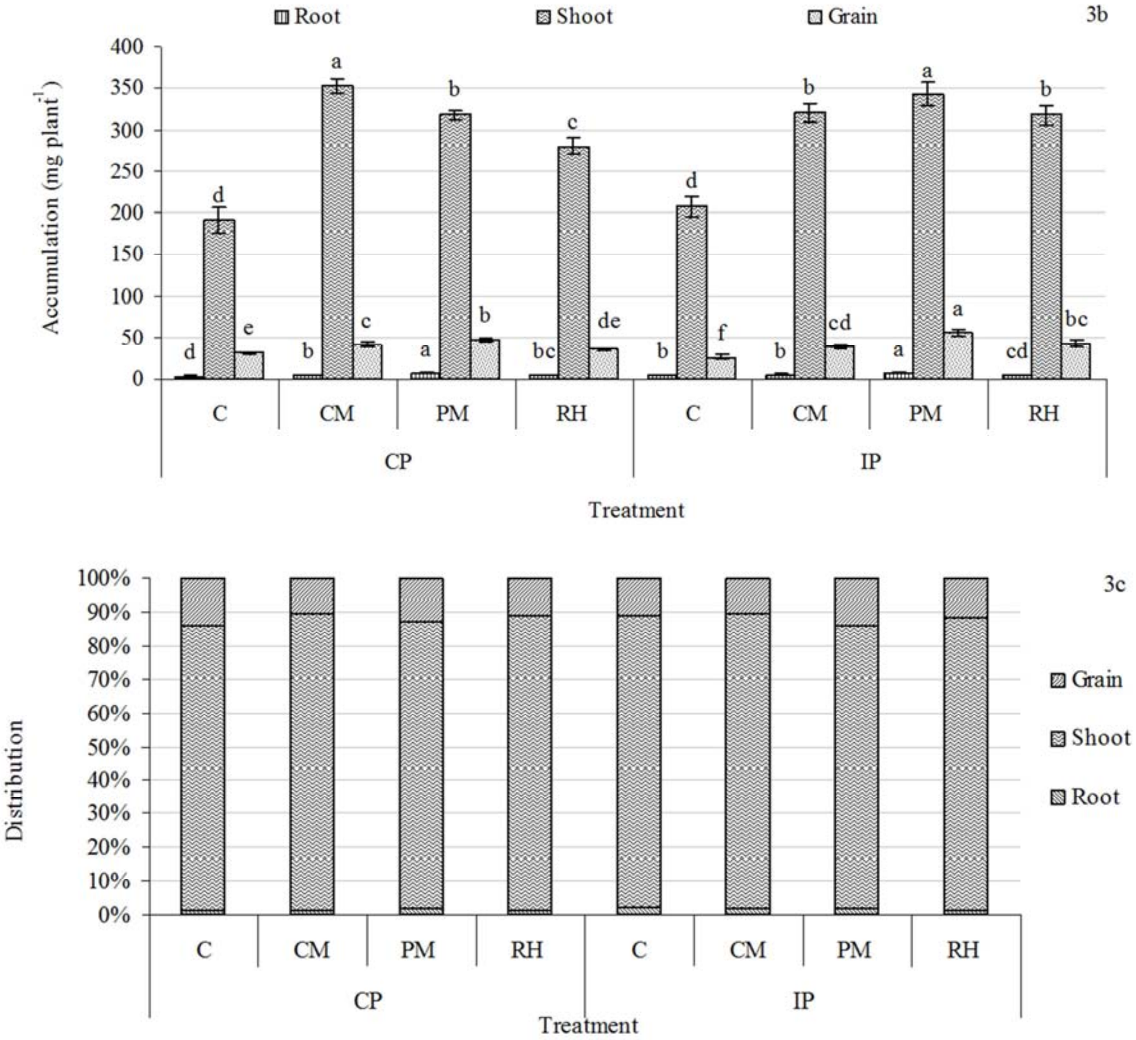
Means followed by the same letter (s) do not differ significantly from each other at 5% level of significance.

Figures 2. *(a-c) Concentration, accumulation and distribution of phosphorus in root, shoot and grain of rice plants at harvesting period.*

3.3. Concentration, Accumulation and Distribution of Potassium in Rice Plants

Figures 3 (a-b) shows the concentration and accumulation of potassium in different parts of rice plants. Potassium concentration was maximum in shoot under both CP and IP conditions followed by grain and root. Similar to phosphorus, the concentrations of potassium in CM and PM treated soils were greater over control. The highest uptake of potassium by plants in PM treated soils was observed under IP condition which significantly varied ($p<0.05$) from other treatments. Except this, no significant difference was found in total uptake of potassium by plants among other organic treated soils. Under CP condition, the uptake of potassium in root was 28, 95 and 50% more in CM, PM and RH amended soils over control, and it was 30, 18 and 12% more in shoot respectively. However, the maximum uptake in grain of 0.83% was found in PM followed by CM (0.76%) and the lowest (0.67%) in RH treated soils. The trend of uptake was also similar in IP condition where, in all parts of plants, the amount of potassium was higher in organic amended soils in comparison to control. The uptake in root was 16, 45 and 3%, 33, 36 and 32% in shoot, and 4, 27 and 17% higher in grain respectively in CM, PM and RH treated soils over control. The variations in concentration among different treatments were highly significant ($p<0.05$) in case of root, shoot and grain. Similar to phosphorus, under both CP and IP conditions, the total uptake of potassium was found in order of PM>CM>RH> C.





Means followed by the same letter (s) do not differ significantly from each other at 5% level of significance.

Figures 3. *(a-c) Concentration, accumulation and distribution of potassium in root, shoot and grain of rice plants at harvesting period.*

Similar to concentration, the accumulation of potassium was higher in shoot followed by grain and root (Figure 3b). The accumulation of potassium in root ranged from 2.91 mg plant^{-1} in control under CP condition to 7.12 mg plant^{-1} in PM treated soils under IP condition, whereas in shoot, the accumulation ranged from 190.91 mg plant^{-1} in control to 352 mg plant^{-1} in CM treated soils under CP condition. The maximum accumulation of potassium in grain was observed in PM treated soils under both CP and IP conditions (47.11 and 55.93 mg plant^{-1} respectively). The soils amended with CM, PM and RH showed 69, 130 and 49% higher accumulation of potassium in root, 85, 66 and 47% higher in shoot and 31, 49 and 14% higher in grain respectively under CP condition. The CM and PM amendments had 8 and 50% more whereas RH treated soils had 25% less accumulation of potassium in root over control under IP condition. However, all organic amended soils had higher accumulation of potassium in shoot and grain over the control. The accumulation of potassium in CM, PM and RH amended soils was 35, 39 and 35% higher in shoot and 49, 113 and 65% higher in grain compared to control. The distribution of potassium ranged from 84.47 to 88.38% in shoot, 1.04 to 1.99% in root and 8.75 to 14.01% in grain (Figure 3c). The distribution of potassium was found in the sequence of shoot>grain>root.

4. Discussion

In an experiment conducted by Shi et al. [2] found that intermittent irrigation resulted in comparatively higher yield of different varieties of rice than flooded irrigation which received almost 37% more water than intermittent irrigation. Jahan et al. [24] postulated that the production of rice can be attained without affecting yield and yield parameters under low water input. Lu et al. [25] also did not find any significant difference on yield of rice grown under different water management systems including continuous flooding, alternate wetting and drying irrigation, saturated soil culture in raised beds, flush irrigation in aerobic soil and rainfed treatments. Several studies revealed the maximum effectiveness of poultry manure on yield and nutrient content of soil and plants compared to other form of organic matter e.g., cow manure and rice straw [16, 26-27]. Whalen et al. [28] reported significantly higher concentration of plant available phosphorus and potassium in manure amended soils compared to non-amended soils.

The less uptake and accumulation of phosphorus under IP condition was not unexpected. Some earlier investigators [29-30] also found that the low uptake of phosphorus by plants was attributed to low soil moisture levels. He and Dijkstra [31] also found stronger negative effects of drought stress on plant phosphorus in the short term (< 90 d), whereas no effects in drying-rewetting cycles. The uptake of phosphorus was found to be very little affected by water potential of as low as -1.2 Mpa [32]. The low content of phosphorus in plant parts may be due to the lower capacity of root to absorb water as well as lower transpiration and active transport of nutrient [33]. The concentration of phosphorus in plant parts was found highest when the topsoil had been maintained wet throughout the growing season compared to alternate wet and dry condition [34]. However, Mackay and Barber [35] found that the total weight of plant, root length and phosphorus uptake by corn increased with increasing soil moisture up to a certain limit and further increase in soil moisture decreased the total weight, root length and phosphorus uptake.

The maximum concentration of total phosphorus and potassium in soils receiving organic amendments may be due to release of these nutrients through the mineralization of manures and ultimately by uptake of plants. The lower uptake of potassium in control under IP condition compared to CP condition indicated lower mobility from soil to plant. A decrease in the concentration of potassium with decreasing soil water tension was postulated in several studies [8, 36]. However, in some plants, water stress had been found to favor potassium uptake [29]. Misra and Tyler [37] observed the highest concentration of potassium at 50-70% water holding capacity of soil. In spite of higher uptake of potassium in control under CP condition, the greater accumulation under IP condition resulted due to increase in total biomass of plant under IP condition. The positive effect on uptake of potassium by plants in PM treated soils under IP condition was believed to be due to the better mineralization of organic matter in alternate oxidation-reduction condition and its subsequent uptake by plants. Sims and Wolf [38] stated higher content of nutrients and more rapid mineralization rate of poultry manure compared to other animal manures. Although water stress can reduce plant nutrient uptake because of reduced nutrient supply through mineralization [39-40], enhanced mineralization has also been suggested by rewetting of soil after drought stress. Rewetting after drought enhances mineralization [41] and the rate is related to the rate and extent of drought, the quantity and distribution of precipitation, temperature, as well as the accessible pool of organic substrates [42].

5. Conclusion

The maintenance of partial aerobic condition in conjunction with incorporation of organic manures were found to increase yield, concentration and accumulation of potassium compared to continuous flooded condition and absence of organic sources. It can be recommended that addition of manures and alternate wetting-drying can be a good approach to minimize the demand of irrigation water while maintaining better yield, uptake and accumulation of potassium.

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