POTASSIUM- THE QUALITY ELEMENT IN ENHANCING PRODUCTIVITY AND ALLEVIATING DETRIMENTAL EFFECT OF ABIOTIC STRESS IN PLANTS

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CERTIFICATE

This is to certify that thesis entitled "Potassium- the Quality Element in Enhancing Productivity and Alleviating Detrimental Effect of Abiotic Stress in Plants" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **DOCTR OF PHILOSOPHY IN SOIL SCIENCE,** *embodies the result of a piece of bona fide research work carried out by* **MOSAMMAT SALMA ZANNAT,** *Registration No. 15-06998 under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

June 2019
Dhaka, Bangladesh

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DEDICATED

TO

MY BELOVED PARENTS,

HUSBAND, DAUGHTER AND SON

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ABSTRACT

Potassium fertilizer management is beneficial for improving growth, yield and yield components of field crops under moisture stress condition. Three field experiments were conducted at the research farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the rabi season of 2016-2018 to evaluate the effects of potassium fertilizer enhancing the productivity and alleviating detrimental effect of abiotic stress along with other recommended fertilizer on the growth, yield, nutrient management, shelf life of the plant product and soil chemical properties, the research was conducted based on selected wheat (BARI gom26), rice (BARI dhan28) and carrot (New Kuroda) variety. The experiments were laid out in Split Plot Design and RCBD method with three replications. The first experiment was conducted on wheat in rabi season with sixteen treatment combination (4 levels of irrigation X 4 levels of K doses) viz. I_0= control (normal irrigations), I_1= Water stress at vegetative stage, I_2= Water stress at flower initiation stage, I_3= Water stress at milking stages and K_0= 0 kg K/ha, K_1= 60 kg K//ha, K_2= 90 kg K/ha, K_3= 120 kg K/ha. Growth and yield contributing characters mainly plant height, number of spikelet's, thousand grains weight of wheat crop were significantly influenced by the potassium fertilizer and water stress at different growth stages. The highest grain yield of wheat (4.04 t/ha) was observed under 120 kg K/ha from I_0K_3 treatment combination, while the lowest grain yield (2.29 t/ha) was recorded from I_0K_1 and I_0K_2 treatment combinations respectively. Among the combined effect of water stress conditions and different doses of potassium I_0K_3combination provided the best result. The second experiment was conducted on rice in rabi season with eleven treatments including control viz. T_1 = Control (no fertilizer), T_2 = Fertilizer recommended dose for BRRI dhan28. (FRD) $N_{120}P_{18}K_{75}S_{13}Zn_{1.5}$, T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg /ha K) from MoP, T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg/ha K) from MoP, T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg/ha K) from MoP, T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg/ha K) from MoP, T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg/ha K) from MoP, T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg/ha K) from MoP, T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg/ha K) from MoP, T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg/ha K) from MoP, T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg/ha K) from MoP. The study in aspect of growth and yield contributing characters mainly plant height, effective tillers/hill, panicle length, filled grain/panicle, thousand grain weight, and harvest index and grain yield of boro rice. The maximum grain yield of rice (6.55 t ha^{-1}) was produced from T_8 treatment which was significantly different from the T_1 treatment (2.35 t ha^{-1}). The third experiment was conducted on carrot with eight treatments including control viz. T_1 = 0 kg K/ha, T_2 = 20 kg K/ha, T_3 = 40 kg K/ha, T_4 = 60 kg K/ha, T_5 = 80 kg K/ha, T_6 = 100 kg K/ha, T_7 = 120 kg K/ha, T_8 = 140 kg K/ha. Storage quality of carrot indicated that after seven days the lowest moisture reduction percentage was observed in K_5 (20.39%) while the highest moisture reduction percentage was found in K_0 (61.45%) followed by K_1 (60.24%). After 14 and 21 days same trend of moisture reduction were found. In room temperature, K_5 treatment provided the best result and enhanced the shelf life of carrot. So, it can be suggested that the improvement of K- nutritional status of plants might be of great importance for the survival of crop plants under environmental stress conditions and potassium fertilizer with other recommended fertilizers would be ideal for better crop growth, increasing yield and shelf life of crops.

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List of Acronyms, Abbreviations and Symbol

AEZ	= Agro-Ecological Zone
ANOVA	= Analysis of Variance
AS	= Ammonium Sulphate
ASN	= Ammonium Sulphate Nitrate
AVRDC	= Asian Vegetable Research and Development Centre
BARC	= Bangladesh Agricultural Research Council
BARI	= Bangladesh Agricultural Research Institute
BAU	= Bangladesh Agricultural University
BBS	= Bangladesh Bureau of Statistics
BRRI	= Bangladesh Rice Research Institute
BSMRAU	= Bangabondhu Sheikh Mujibur Rahman Agricultural University
CD	= Cowdung
CIMMYT	= International Maize and Wheat Improvement Centre
Cm	= Centimeter
CV	= Coefficient of Variance
DAP	= Days After Planting
DMRT	= Duncan's Multiple Range Test
e.g.	= Exempli gratia (by way of example)
Ed.	= Editor
EPBS	= East Pakistan Bureau of Statistics
et al.	= And others
FAO	= Food and Agriculture Organization
Fig.	= Figure
FYM	= Farm Yard Manure
G	= Gram
ha^{-1}	= Per Hectare
HI	= Harvest Index
IRRI	= International Rice Research Institute
J.	= Journal
L	= Liter
LAI	= Leaf Area Index
LLP	= Low Lift Pump
LSD	= List Significant Difference
meq	= Milliequivalent
mgL^{-1}	= Milligram
MoP	= Muriate of Potash
MSS	= Mean Sum of Square
NARS	= National Agricultural Research System
NS	= Non Significant
NUE	= Nutrient Use Efficiency
^{o}C	= Degree Centigrade
p.	= Page/pages
PI	= Panicle Initiation
ppm	= Parts Per Millions
Pub	= Publication
RCBD	= Randomized Complete Block Design
RD	= Recommended Dose
RDF	= Recommended Dose of Fertilizer
Res.	= Research
RFD	= Recommended Fertilizer Dose
SAU	= Sher-e-Bangla Agricultural University
Sci.	= Science
t	= Tone
TSP	= Triple Super Phosphate

HYV	= High Yield Variety	UN	= United Nation
i.e	= edest (means That is)	var.	= Variety
IFDC	= International Fertilizer Development Centre	VFRC	Virtual Fertilizer Research Centre

CHAPTER I

Introduction

Bangladesh is a densely populated and agriculture based country. Agriculture is the main stem of livelihood for more than 80% of the country's population. The main purpose of agriculture is to provide food for the increasing population. Fertilizer is considered one of the main inputs for increasing crop yields and farmer's profit. To understand the role of fertilizer for increasing production, Tandon and Narayan (1990) cited the Nobel prize-winning wheat scientist Dr. Norman E Boralaug's dialogue as *"If the high yielding wheat and rice varieties were the catalyst that ignited the green revolution, then chemical fertilizer was the fuel that poured its forward thrust".* It is true for Bangladesh agriculture because it has virtually no possibility of increasing its cultivable land area. To increase production as well as maintain the quality of crop balanced fertilization can serve as a possible solution. It includes supplying of nutrients elements like nitrogen, phosphorus, potassium, sulphur, zinc etc. in a proper manner. Among these nutrients potassium holds a very important role in improving crop quality and increases its ability to fight against stress.

Potassium (K) is a soft, silver-white metal, light in its pure form that reacts very violently with water. It is commonly called potash (K_2O), a term that has been derived from an early production technique where K was leached from wood ashes and concentrated by evaporating the leaching in large iron pots (Mikkelsen and Bruulsema, 2005). Soils contain varying quantities of K-bearing minerals that constitute a major K reserve. The K reservoir in the earth crust is associated with primary alumina silicates that are the most abundant K-bearing minerals such as K feldspar, mica, biotite, muscovite and nepheline.

Potassium is an indispensable constituent for the proper development of plants. It is important in photosynthesis, regulation of plants responses to light through opening and closing of stomata. Potassium has importance also in the biochemical reactions in plants. Predominantly, potassium (K) is responsible for many other vital processes such as water and nutrient transportation, protein, and starch synthesis. Among all other nutrients, potassium is one of the most essentials and major nutrient for production of crop (Zhang *et al.,* 2011). The role of potassium is well known for improving shelf life of crops and disease resistance (Khawilkar and Ramteke, 1993). Therefore, it is essential for the growth and metabolism of plants; the deficiency of potassium in plants causes poorly developed roots, slow growth and low resistance to disease, delayed maturity, small seeds, yellowing of leaves, falling off the margin of the leaves, also lead to defoliation and ultimately resulting in reduced yield. Reduced availability of potassium directly results in less fluid circulation and trans-location of nutrients in plants. This directly make plants susceptible to temperature fluctuation.

With rapid development of agriculture with intensive cropping or due to application of imbalanced fertilizers, available K level in soils has dropped. Potassium is reported to improve water relations as well as productivity of different crops under water stress conditions (Johnson 1983, Islam *et al.* 2004). Mengel and Kirkby (1987) reported that several biochemical pathways, osmotic potential translocation process, and growth and maintenance of a cell are dependent on potassium ion in the cell sap. However, non-judicious application of potassium fertilizer in the field may create harmful effects on crop productivity as well as environmental problems.

Potassium is effective in the synthesis and transport of carbohydrates and carbon dioxide and is necessary for the formation of thick-walled cells. Potassium enhances product quality, and increases efficiency of photosynthesis, increases plant resistance against some diseases. Potassium is essential element for the formation of large resistant stem in cereal (Khajepour, 1995).

Potassium is a major nutrient element that plays an important role in several metabolic process such as protein synthesis and osmotic adjustment (Marschner, 1995). Maintenance of high cytoplasmic levels of K^+ is essential for survival of plants in stress environment (Chow *et al.*, 1990). Hanway and Johnson, (1985) reported that application of high level of potassium increased leaf K content and seed yield of soybean under drought stress conditions. Premachandra *et al.* (1993) noticed that external application of potassium helps in the active photosynthetic processes in two ways. First, K^+ affects photosynthetic capacity, possibly because of the dependence of protein synthesis and developmental process on K^+. Thus, the gas exchange of an expanding leaf is restricted rapidly after the onset of K^+ deficiency. Second, K appears to affect the activity of photosynthetic system, which becomes evident when a mature leaf becomes K deficient (Huber, 1985). In this regard, Peaslee and Moss (1968) reported that photosynthesis in K deficient corn leaves increased when K was supplied through transpiration stream. All those reports support the findings of this study that high level of K enhances plant growth and yield of wheat under water shortage conditions.

Association between K stress and plant drought resistance has been demonstrated by many workers. Drought can be defeated by plants by inducing deeper rooting, larger absorption surfaces and greater water retention in plant tissues, which can also be overcome by application of K fertilizers with other nutrients like phosphorus and nitrogen (Kirkby *et al.*, 2009). Sufficient amounts of K enhance the total dry mass accumulation of crop plants under drought stress/low-moisture conditions in comparison to lower K concentrations (Egilla *et al.,* 2001). Similar findings were documented by Lindhauer, (1985) that not only plant dry mass was increased but also leaf area and water retention in plant tissues under drought-stressed conditions improved. It was found that plants that were continuously exposed to drought stress could form reactive oxygen species, which caused leaf damage (Cakmak, 2005; Foyer *et al.,* 2002). Wang *et al.* (2013) found a close relation of K in physiological and molecular mechanisms of plant drought resistance. For the period of drought stress, root growth and the rate of K^+ diffusion in the soil towards the root got restricted and depressed the plant resistance as well as K absorption.

Rice is more susceptible to many plant diseases when K nutrition is low or deficient, which can cause yield and quality losses beyond that caused from the physiological effects of insufficient K nutrition. High incidence of brown leaf spot (*Bipolaris oryzae*), stem rot (*Sclerotium oryzae*) and other opportunistic diseases are important signs of potential K deficiency in rice (Slaton *et al*. 2009). Since K is a macronutrient and is taken up in large amounts, application of granular K fertilizer followed by irrigation or a timely rainfall is the salvage practice commonly practiced but application of K in different integrations of other nutrients might bring up a spectacular result in rice growth as well as yield.

Farmers of Bangladesh are not interested to apply K fertilizers or use very low amount of it for rice cultivation because they can't see the immediate visual result of K application. Moreover, farmers are not efficient enough to identify the K deficiency symptoms of crop plant. For this reasons, intensive cropping with increased N and P fertilizer, yield response of rice to K fertilization become more evident (Yang *et al.*, 2003). Yield response to applied potassium is a function of crop, variety, soil characteristics, attack of pest and diseases and application of other nutrients. Rice tends to respond more to potassium than wheat. Possibly, due to retarded respiration rates of roots under anaerobic soil conditions, adequate absorption of potassium by rice roots can only be ensured by high potassium levels in the soil. Potassium is essential for utilization of nitrogen. So, the K fertilizations ensure the proper root growth and uptake of the other nutrient which ultimately increase the crop growth and development.

In Bangladesh, so many researchers' activities were taken to initiative on nutrient or fertilizers management especially nitrogen and phosphorus like effect, doses and timing etc but no enough research on role of potassium on rice, water stress condition of wheat and shelf life capability on carrot. Proper soil fertility management emphasizing balanced fertilization is one of the most important cultivation technique that ensure optimum supply of nutrients for successful crop production and maintenance of soil health. The supply of nutrients to the soil - plant system comes from various sources.

K is important for successful carrot (*Daucus carota* L.) production. Nutrient K has significant effect on the shelf life of carrots. Under hydroponic system, increased K concentration in nutrient medium reduced the post harvest moisture loss of carrot. Root weight, tissue K concentration increased while water potential, osmotic potential and solute leakage decreased with rising K content (Shibairo *et al.*, 1998).

Water stress adversely affects plant establishment, and there after growth and development. Cell enlargement, gas exchange and assimilates partitioning are hindered by the stress. Under extreme conditions, it may severely disturb several metabolic processes, which may result in diminished photosynthesis, checked cell enlargement and division, and finally cell death (Kramer, 1983). Water stress as the reproductive stage is more harmful to plant processes than that any other growth stages. This is because water stress at a thesis markedly photosynthesis, reproductive development and finally grain yield (Karim *et al.,* 2000).

From the above aspect, the present study was conducted to investigate the effects of water stress condition and fertilizer on the growth, yield contributing characters and quality enhance the nutrient uptake, the productivity of selected crop wheat, rice and carrot.

Considering the above facts, the present study was, therefore, undertaken with following objectives;

I. To evaluate the effect of potassium on growth and yield of wheat, rice and carrot.

II. To investigate the effect of water stress condition along with other recommended fertilizers to enhance the productivity of plants.

III. To evaluate the prospective of shelf life technologies for better quality of plant products.

IV. Identifying the common or specific response of K to distinct stress and the role of K on long-term plant responses under multiple stress conditions in nature.

CHAPTER II
Review of Literature

An attempt has been made in this chapter to present a brief and relevant review of many researchers in relation to the three experiments conducted by the author. Here reviews have been added regarded to effect of potassium on the growth and yield of wheat under water stress condition, integrated nutrient management for boro rice to check potassium balance in soil and improving quality and shelf life of carrots by applying potassium in soil.

Experiment 1: Effect of potassium on the growth and yield of wheat under water stress condition

2.1.1 Impact of potassium on alleviating water stress condition in wheat

Among the different stresses, drought is the most alarming one that effect agriculture and its production worldwide especially in arid and semi-arid regions. Reactive oxygen species produced during different physiological processes such as photosynthesis, photo-respiration, photo-oxidation and in-activation of hill energy under stress conditions. These reactive oxygen species affect the performance of plants and damage the cell that play role to mitigate the stress (Boutraa *et al.,* 2010). Under arid and semi-arid environment crop plants remained under stress conditions, but drought stress is the most alarming one that effects growth and development of crops and caused huge economic loss as result of complete failure of the crop under these situations (Abbas *et al*., 2015, Ali *et al*., 2013, 2014, 2016). The degradation of soil resources occurred as result of imbalance use of fertilizer as well as nutrient mining due to high cropping intensity which caused reduction in yield up to 68 % and 64 % correspondingly, in wheat and rice (Mahmood *et al*., 2016). Among different mineral nutrients, potassium plays an important role to control the adverse effect of drought. Application of potassium sulphate in solution as well as in fertilizer form enhanced biomass production and availability of some essential nutrients such as potassium, calcium, magnesium and phosphorus in saline soils. Potassium plays a vital role in increasing efficacy of photosynthesis, protein synthesis, enzyme activation, osmo-regulation, energy transfer, stomatal movement, cation-anion balance and stress resistance (Kausar and Gull, 2014). Potassium is vital for growth as an enzyme activator that promotes metabolism. K provides abiotic stress tolerance (e.g., under drought stress), regulate stomatal opening and helps plants adapt to water deficit (Hasanuzzaman *et al*., 2018). Potassium application in stress conditions helped to improve the peduncle length, number of grains per spike, biological yield and grain yield as compared to normal conditions (Ghaznavi and Abdolshahi, 2011). Adequate amounts of potassium required by most of plants to tolerate drought stress and perform well to give optimum yield. It serves as a primary osmotic to balance the turgor pressure of plants under stress environment. Potassium had an important role to mitigate the effects of drought stress by increasing nitrate reductase assimilation, K+ ion accumulation, free proline, glycinebetaine and soluble protein (Zhang *et al*., 2014). In the presence of biotic and abiotic stresses, it plays a vital role to mitigate them and also increases the abilities of plants to survive under stress environment. To adjust osmotic potential, sustain a higher turgor pressure and relative water content, crop needs an ample supply of K to enhance its capacity to stand under these conditions (Wang *et al.,* 2013). Adequate amount of potassium increased root penetration by making soil soft and porous. It enhanced ability of roots to absorb nutrient and water from large volume of soil. It increased resistance capacity of plants to cope with drought stress environment (Ebrahimi *et al.*, 2014). Potassium is a vital macro nutrient that enhanced the capacity of plants to cope with different biotic and a-biotic environmental stresses. It also has positive affect to meet the current food requirement by improving crop yield and quality of produce under water shortage conditions (Aslam *et al*., 2014). Drought stress influenced accumulation of potassium in leaves. The mechanism of stomatal opening is greatly dependent on potassium concentration (Pranckietiene *et al.*, 2015). The application of macronutrients (Ca^{2+} and K^{+}) shows the positive role in mitigating the adverse effect of drought stress in the plant. Under drought, application of K^{+} /Ca^{2}+ at higher rate increased the resistance in wheat varieties against these conditions (Majid *et al*., 2007). Potassium played an important role in mitigating harmful effect of drought stress and acted as an indicator/ preventing agent to water stress conditions. Application of adequate amount of potassium fertilizer reduced negative effect of drought on grain yield of a crop (Fooladivanda *et al.*, 2014). Application of potassium fertilizer significantly enhanced plant root length and penetration to uptake water and absorb nutrients in large volume of soil. Potassium plays a vital role to tolerate the drought stress and helps plant to grow normally by maintaining their turgor pressure. In arid and semi-arid regions a farmer should need to estimate soil potassium supply and apply recommended dose to protect the environment (Valadabadi and Farahani, 2010). Plant's dry matter accumulation, grain yield and uptake of N, P and K may be enhanced with an optimum amount of K nutrition. It may help in reducing the lethal effects of drought stress in wheat crop (Baque *et al.*, 2006).

Malek *et al*. (2013) conducted an experiment to find out the effect of potassium sulfate and zinc fertilizers on wheat drought resistance under water stress conditions. In this test, a split factorial in a randomized complete block design with three replications. Factors examined include the normal irrigation and supplemental irrigation in main plots were performed and potassium fertilizers concentrations of zero. 60, 120 and 180 kg ha potassium sulfate source and zinc concentrations zero and 25 kg ha of zinc sulfate source factorial subplots were performed. At the end of the experiment seed yield, number of grains per spike, number of spikelets per spike, 1000 seed weight and the amount of protein, potassium, zinc and nitrogen on grain measured. The results showed that potash fertilizer had a positive effect on most traits.

Water stress causes serious yield loss of wheat (*Triticum aestivum* L.) under non irrigated condition. Baque *et al.* (2006) initiated a study to analyze whether potassium (K) fertilizer improves the water stress tolerance in terms of growth, yield and nutrient uptake of this crop. A popular wheat variety in Bangladesh, Satabdi was grown in poor nutrient soils inside plastic greenhouse under natural light. Three levels of potassium (K) (low: 39, medium: 156 and high: 312 $kgha^{-1}$) and three levels of soil moisture namely control (less than 25% depletion from field capacity, FC), mild stress (more than 37.5% depletion from field capacity, FC) and severe stress (more than 50% depletion from field capacity, FC) were the applied treatments. Water stress affected significantly dry matter accumulation in leaves, stems, spikes and roots. Uptake of N, P, K was lowered by water stress. Consequently, most of the yield contributing characters as well as grain yield were reduced. Higher levels of K improved the dry matter accumulation in different plant parts. Yield and yield contributing characters also improved by the application of high level of K application irrespective of the level of soil moisture in wheat. N, P, K uptake was also increased with increasing levels of K, especially under water stress condition. It was concluded that higher levels of K (greater than recommended dose) application might mitigate the adverse effect of water stress on wheat productivity.

Aown *et al.* (2012) studied to find out the response of wheat (*Triticum aestivum* L.) cultivars to foliar application of 1% potassium at different growth stages (tillering, flower initiation and milking) was carried out under water limited environment, at the Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad. Various agronomic traits (plant height, spike length, number of spikelets per spike, number of grains per spike, 1000-grains weight and grain yield per plant) of crop were recorded using standard procedures. Drought stress at all three critical growth stages adversely affected plant height, spike length, number of spikelets per spike, number of grains per spike, 1000-grain weight and grain yield of wheat plant. Foliar application of K at all three critical growth stages improved the drought tolerance of plants and improved the growth and yield components, however, grain filling stage was found more responsive.

Saren and Jana (2008) conducted a field experiment in West Bengal. India, in winter to study the effects of irrigation depth (4.5. 6.0, 9.0 and 12.0 cm), with the half rate of N (urea) and fill rate of P (50 kg single super phosphate/ha) and K (50 kg muriate of potash/ha) were applied as basal. The application of 50 kg K/ha as top dressing after irrigation gave the longest plant. Highest length of spike, number of effective tillers, grains and straw yields and N. P. K uptake by grain and straw.

A field experiment was conducted by Akram (2011) to determine the sensitivity of wheat to water stress and changes in water relations and yield of wheat (*Triticum aestivum* L.) under water stress conditions applied at different growth stages. The experiment comprised of two wheat cultivars and four water stress treatments, maintained by withholding water at tillering, anthesis, and at both stages. Water stress caused reduction in leaf relative water contents, water potential, osmotic potential, turgor potential, growth and yield components of both the wheat cultivars. The results indicated that high value of relative water contents was associated with increased yield and yield components. Consecutive stresses at both growth stages caused severe reduction in yield and yield components in both cultivars of wheat.

2.1.2 Effect of potassium on growth and yield parameters of wheat

Potassium is one of the principle plant nutrients underpinning crop yield production and quality determination. While involved in many physiological processes, potassium's impact on water relations, photosynthesis, assimilate transport and enzyme activation can have direct consequences on crop productivity. Potassium deficiency can lead to a reduction in both the number of leaves produced and the size of individual leaves. Potassium (K^+) is one of major nutrients considered essential for crop growth and yield development, although it is not an integral component of any cellular organelle or structural part of the plant. It is the most abundant cation in plants and is associated or involved with many of the physiological processes supporting plant growth and development (Pettigrew, 2008).

The influence of potassium is mainly an aggregate of the functions played by nutrients in mitigating negative effects of biotic and abiotic stresses. Plants provided with sufficient amounts of potassium are less vulnerable to water deficiency, low temperatures and pathogen attacks (Ma *et al*., 2006). Potassium yield-stimulating functions are different, which stems from their differentiated influence on the plant growth during the vegetation period.

Potassium is an indispensable component during the main stages of protein biosynthesis. Its deficiency leads to a decrease of protein amount produced by a plant, and this effect occurs regardless of the nitrogen nutrition level and accumulation of non-protein nitrogen, the presence of which fosters fungal infections (RICE, 2007). Furthermore, potassium deficiency impedes nitrogen uptake and, as a result, the growth of leaf assimilation surface; it also reduces the uptake and transport of nitrates in plants (Marschner *et al*., 1996).

Potassium is also important in the transportation of prepared food from the leaves to the rest of the plant parts, quality of seeds and fruits, strengthens the roots, stem and branches of plants and reduce lodging. Potassium fertilization had shown yield improvement of crops in various areas of the world (Imran and Gurmani, 2011). Research findings in India, Bangladesh and Iran indicated that Potassium fertilizer increased grain and straw yield of wheat at various rates (Astatke *et al.*, 2004; Malek-Mohammadi *et al.*, 2013; Saha *et al.*, 2010; Tabatabaei *et al.*, 2012).

Maurya *et al.* (2014) conducted an experiment during Rabi season to study the effect of potassium levels on growth, yield and economics of wheat (*Triticum aestivum* L.) varieties. Treatments were consisting of three varieties of wheat viz. PBW-343, K-307 and K-402 and four potassium levels viz. 0, 40, 60 and 80 kg K ha^{-1} in factorial randomized complete block design with 3 replications. Significantly higher growth characters viz. no. of ear head (391.2 m^{-2}), effective tillers (266.4 m^{-2}) and total number of tillers (317.5 m^{-2}); yield attributes viz. length of $spike^{-1}$ (9.3 cm), no. of spikelets $spike^{-1}$ (19.9), weight $spike^{-1}$ (2.6 g), grains $spike^{-1}$ (46.30) and weight of grains $spike^{-1}$ (1.83 g) were recorded with PBW-343 followed by K-307 and the lowest in K-402. Similarly, the highest grain yield (48.8 q ha^{-1}), straw yield (69.7 q ha^{-1}) and biological yield (118.6 q ha^{-1}) were also recorded in wheat variety PBW-343. Gross returns (Rs. 80, 041 ha^{-1}), net returns (Rs.37, 620 ha^{-1}) and B: C ratio (1.88) was found in the variety PBW-343. Higher growth characters and yield attributes of wheat were reported with application of 80 kg K_2O ha^{-1}. Similarly, the highest grain yield (50.7 q ha^{-1}), straw yield (70.1q ha^{-1}), biological yield (120.9 q ha^{-1}) and harvest index (41.9%) were also recorded under 80 kg K_2O ha^{-1} which was at par with 60 kg K_2O ha^{-1}.

Beckett and Staden (1989) investigated the effects of the seaweed concentrate 'Kelpak' on the growth and yield of wheat grown under conditions of varying K supply. Kelpak had no significant effect on the yield of wheat receiving an adequate K supply, but significantly increased the yield of K stressed plants. The increase in yield was caused by an increase in both grain number and individual grain weight. Although the beneficial effects of seaweed concentrates have often been attributed to their cytokinin content, several lines of evidence suggested that this group of plant growth regulators may not be solely responsible for the observed effects of Kelpak on wheat. Irrespective of the physiological mechanism of action, Kelpak would appear to have considerable potential for increasing yield in K stressed wheat and may therefore reduce the requirement of wheat for K fertilization.

Pettigrew (2008) studied Potassium as one of the principle plant nutrients underpinning crop yield production and quality determination. While involved in many physiological processes, potassium's impact on water relations, photosynthesis, assimilate transport and enzyme activation can have direct consequences on crop productivity. Potassium deficiency can lead to a reduction in both the number of leaves produced and the size of individual leaves. Coupling this reduced amount of photosynthetic source material with a reduction in the photosynthetic rate per unit leaf area, and the result is an overall reduction in the amount of photosynthetic assimilates available for growth. The production of less photosynthetic assimilates and reduced assimilate transport out of the leaves to the developing fruit greatly contributes to the negative consequences that deficiencies of potassium have on yield and quality production. Goals aimed toward increasing crop productivity and improved quality dictates either increased potassium supply or more efficient use of potassium. Developing plants that more efficiently use potassium might be a worthwhile goal for geneticists.

In field experiment by Tahir *et al.* (2008) at Faisalabad, Pakistan to study the effect of control, 30, 60, 90 kg K ha^{-1} on two wheat cultivars Inqlab91 and Ufaq-2002. Fertile tillers m^{-2}, number of grains $spike^{-1}$, 1000-grain weight and grain yield were significantly increased by increasing K level. The crop fertilized at the rate of 90 kg K ha^{-1} gave significantly higher yield, but on the basis of economic analysis it is recommended that crop fertilized with 60 kg K ha^{-1} gave better results. As for as varieties are concerned, Inqlab-91 respond more to K level than Ufaq-2002.

Hussain *et al*. (2002) investigated into the effect of three N, P and K levels (35-25-25, 70-50-50 and 105-75-75 kg ha^{-1}) on growth, yield and quality of three wheat varieties i.e. Inqulab-91, Kharchia and Parwaz-94 were carried out at Agronomic Research Area, University of Agriculture, Faisalabad. Different NPK levels significantly affected plant height, Number of fertile tillers, 1000-grain weight, grain yield and grain protein content of wheat. The highest grain yield (4.99 t ha^{-1}) was recorded in Inqulab-91 with the application of 105-75-75 kg NPK ha^{-1}.

Rao (1986) studied potassium (K) requirements for growth- dry matter (DM) and leaf area (LA) and related processes, relative leaf growth rate (RLGR), relative growth rate (RGR), net assimilation rate (NAR) and crop growth rate (CGR) were determined by plant analysis during the entogeny of wheat. Wheat (*Triticum aestivum* cv. HD 2329) plants were supplied with different amounts of K from deficient to adequate through nutrient solution. Samples were taken at specific stages for K determinations. The DM and LA were recorded at 45 days, 75 days and 105 days. The growth-related processes RGR, NAR and CGR were estimated between 30-45 days, 45-75 days and 75-105 days. In case of RLGR the observations were carried out between 15-30 days, 30-45 days and 45-75 days. These physiological processes and grain yield were correlated with K concentration in whole plant at 30 and 45 days and top two leaves at 75 and 105 days. The results indicated that K status in plants influences growth mostly through leaf area formation which in turn influences successively RLGR, RGR and CGR and finally grain yield. For vegetative growth the optimum concentration required in plants was always lower than the optimum for grain production.

Meena *et al.* (2015) studied the effect of concentrate organic manure (well grow grain and well grow soil) and NPK improved the growth and yield of wheat. Significant improvement in terms of growth parameters like plant height, tillers, dry matter production and productive tillers with application of 120: 60: 60 NPK + 300 kg well grow soil/ha and at par with application of 120: 60: 60 NPK + 300 kg well grow grain/ha, treatment receiving 100% NPK + 300 kg well grow soil/ha resulted maximum grain yield (4545 kg /ha). Treatment of 100% NPK + 300 kg well grow grain/ha maintained higher straw yield (5715 kg/ha) and test weight (44.10 g) due to application of 100 % N, P, K along with 200 kg well grow soil/ha whereas it was at par with application of 75 and 100% N, P, K with both levels of well grow formulation.

Zhang *et al.* (2000) measured various crop response to a mixed municipal solid waste (refuse) bio-soilds co-compost (named Nutrin Plus) and examined the fate of certain metals associate with Nun-i Plus compost. There were six treatments: check 50, 100 and 200 t compost ha^{-1}. NPKS (75 kg N ha^{-1}, 20 kg P ha^{-1}, 45 kg K ha and 18kg S ha^{-1}), PK (2kg P.45 kg K ha^{-1}), and three crops: rape, wheat and barley. The research results showed that the compost slightly increased heavy metal concentrations in the soil but did not cause and photo-toxicity to crops. Yield from 100 and 200 t ha^{-1} compost application was higher than with NPKS treatment. However, the yield of 50 t ha^{-1} compost application was similar to that of NPKS treatment. The compost apparently was more beneficial in the year of application. The results suggested that Nutri Plus compost application generated positive yield responses in all three crops. Crop yield increased as the application rate increased.

Wheat has proved to have a higher agronomic K efficiency as indicated by a greater relative yield under K deficient conditions (El *et al.,* 2002). Better growth and yield of wheat crop has been observed with the addition of' K (Singh *et al.,* 2000), Potassium content in the plant tissue is crucial to the proper functioning of several important biochemical and physiological processes that directly determine crop productivity. Alam *et al* (2009) revealed that yield contributing characters and yield exerted significant variation due to application of different levels of K and the best performance of the crop parameters was recorded when 36 kg K/ha was applied. Remarkable increase in grain, straw and total biomass yield was recorded in the same treatment.

Brhane *et al. (*2017) depicted that plant height and harvest index were not significant. However, spike length, grain yield and straw yields of wheat were significantly affected by K application rates. Hence, the highest spike length was obtained at a rate of 90 kg/ha K_2O but the highest grain and straw yield of wheat were obtained at 30 kg/ha K_2O. Besides, the highest apparent K recovery and agronomic use efficiency were found at 30 kg K_2O/ha.

Application of potassium fertilizer and zinc significantly improved the growth and yield parameters of wheat. The results revealed that the application of increasing levels of potassium and Zinc up to @ 30 and 60 kg/ha and 25 and 50 kg/ha, respectively significantly increased the growth parameters viz., number of leaves plant^{-1}, dry weight (g) at different growth stages and yield attributing characters like length of ear head, number of grains ear^{-1}, test weight (g), grain and straw yields but harvest index non-significant with as compared to control.

From the above review of literature, it is evident that potassium fertilizer has a significant influence on yield and yield components of wheat. Reduction in grain yield is mainly attributed by the reduced number of spike plant, grains and thousand grain weights due to curtailment of period for development of these parameters.

Experiment 2: Integrated nutrient management for boro rice to investigate potassium balance in soil

2.2.1 Impact of potassium on growth and yield parameters of rice

Islam and Muttaleb (2016) studied effect of potassium (K) fertilization (0, 20, 40, 60, 80 and 100 kg K ha^{-1}) on yield, nitrogen (N) and K nutrition of Boro (dry season) rice and apparent soil K balance was. Experiment was conducted at Bangladesh Rice Research Institute (BRRI) regional station, Habiganj, Bangladesh in a wetland rice ecosystem under haor area. A popular rice variety BRRI dhan29 was tested in a randomized complete block design with three replications. Results indicated that BRRI dhan29 maintained an average grain yield of 5.19 t ha^{-1} $year^{-1}$ without K fertilization. Potassium fertilization significantly increased the grain yield to 6.86 t ha^{-1} $year^{-1}$. Quadratic equations best explained the progressive increase of rice yield with increasing K rates. Optimum dose of K in 3 years ranged from 78 to 93 kg ha^{-1}. Internal N use efficiency of rice decreased with increasing K rates. However, K use efficiency was inconsistent. Apparent K balance study revealed that application of 100 kg K ha−1 was not able to maintain a positive K balance in soil under wetland ecosystem with Boro–Fallow–Fallow cropping system. However, K fertilization decreased the negativity of K balance in soil.

Wang *et al.* (2013) found potassium (K) as an essential nutrient that affects most of the biochemical and physiological processes which influence plant growth and metabolism. It also contributes to the survival of plants exposed to various biotic and abiotic stresses. The study focused on the emerging role of K in defending against a number of biotic and abiotic stresses, including diseases, pests, drought, salinity, cold and frost and waterlogging. The availability of K and its effects on plant growth, anatomy and morphology as well as plant metabolism were discussed. The physiological and molecular mechanisms of K function in plant stress resistance were also observed.

Regmi *et al.* (2002) found that both rice and wheat responded to K application but the response of wheat was substantially higher, indicating that the availability of native K may have been lower in wheat. Rice yields were lower in treatments without P than with P, and yields declined significantly. Wheat yield was more adversely affected than rice yield when P and K were not applied. In addition, wheat yields were low. The interaction of K deficiency with *Helminthosporium* leaf blight (spot blotch and tan spot) is also suggested as one of the factors limiting wheat yields. The estimated K balance in soil was highly negative. Results suggest that farmers should apply adequate amount of K for higher and sustainable rice and wheat yields.

Sarwar (2012) evaluated the effects of potassium (K) application rates on rice yield using cultivar "Shua-92". The treatments were consisted of K applications at 40, 50 and 60 kg/ha at the top dressing, and no K fertilizer application along with normal doses of nitrogen and phosphorous. The results showed that compared with the untreated control, K fertilizer increased paddy yield. The treatments 50 and 60 kg K significantly increased the grain yield of rice, but none significantly followed by application at 40 kg compared to control treatment. This assures that at low level of K application, biomass of rice plants was significantly less than the plants grown in the higher levels, but further increase in the amount of K from 50 to 60 kg/ha did not significantly increase the biomass of rice plants. The results suggest that application of K fertilizer could be safely and successfully managed to contribute larger volume of yield, reduced damage of stem borer and environmental pollution.

Uddin *et al.* (2013) conducted an experiment to assess the influence of nitrogen and potassium on the yield response of NERICA 1 rice. five levels of nitrogen 0, 20, 40, 60 and 80 kg N ha^{-1} from urea and four levels of potassium viz. 0, 20, 40 and 60 kg K_2O ha^{-1} from muriate of potash was applied using randomized complete block design with three replications. Results revealed that application of nitrogen at 80 kg ha^{-1} produced the highest number of total spikelets and maximum number of grains $panicle^{-1}$ resulted in the highest grain yield. In case of potassium, the highest number of total tillers and effective tillers, maximum number of total spikelets and grains $panicle^{-1}$ resulted in the highest grain yield from 40 kg K_2O ha^{-1}. The interaction of nitrogen and potassium showed significant effect on all the parameters except 1000 grain weight. Simultaneous application of 80 kg N ha^{-1} and 40 kg K_2O ha^{-1} produced the highest grain yield in NERICA 1 rice. A functional positive relationship was observed between effective tillers and grains $panicle^{-1}$ with grain yield of NERICA 1 rice and it was linear. Based on the results it may be recommend that nitrogen and potassium should be applied at 80 kg N ha^{-1} and 40 kg K_2O ha^{-1} for obtaining the higher grain yield of NERICA 1 rice.

Ding *et al.* (2006) observed the interaction of magnesium (Mg) with potassium (K) in rice (*Oryza sativa* L.). Excess of Mg (more than 3.0 mg g^{-1} DW in the shoot), together with low K supply, suppressed NR (nitrate reductase) activity and decreased concentration of soluble sugar in the leaves. There were great antagonistic and moderately synergistic effects between K and Mg, but the effects of K were much more significant than those of Mg on their uptake and translocation, NR activity and net photosynthetic rate in the leaves. The optimum weight ratio of K to Mg ranged between 22 and 25 in the leaves at tillering stage. Mg deficiency was not compensated for by moderate supply of K but was aggravated by excess supply of K, suggesting specific roles of Mg in both dry matter production and partition of carbon assimilates in rice.

Slaton *et al*. (2009) observed that, rice and soybeans are more susceptible to many plant diseases when K nutrition is low or deficient, which can cause yield and quality losses beyond that caused from the physiological effects of insufficient K nutrition. High incidence of brown leaf spot (*Bipolaris oryzae*), stem rot (*Sclerotium oryzae*) and other opportunistic diseases are important signs of potential K deficiency in rice. Generally, on soils with sub optimal soil K availability, rice and soybean yields are maximized and disease susceptibility minimized when sufficient K is applied pre plant or early post emergence. Mid and late season K fertilizer applications of granular fertilizer to K-deficient rice and soybeans can produce significant yield increases, but the magnitude of yield increase usually declines as K fertilization is delayed. Although foliar feeding may reduce yield loss from K deficiency, only small amounts of K can be applied in a single application without significantly burning plant leaves. Since K is a macronutrient and is taken up in large amounts, application of granular K fertilizer followed by irrigation or a timely rainfall is the salvage practice most commonly recommended.

Timsina *et al*. (2010) found that improved K management may have great potential for improving the overall productivity of Rice maize (R-M) systems of South Asia, but will require special consideration on soils containing K-fixing minerals. As with P, it may seem appropriate to make differential applications of K to component crops in R-M systems on non-K fixing soils, again with least K applied to rice with the aim of preventing loss by leaching. Finally, occurrence of K deficiency and response to applied K depend on yield level, K buffering capacity of the soil, straw management, and net K inputs from sources other than fertilizer. Along with K inputs from sediments deposited from flood plains and flood water while formulating a rational K management strategy for R-M systems. Application of full maintenance rate of K (input = output) may not be profitable for rice and maize under situations where crop response to K is poor. In such soils, such as in Bangladesh, some K mining may be allowed by applying K below maintenance rate.

K helps to improve root growth and plant vigor, prevent lodging and improve resistance to unfavorable weather conditions, enhance crop resistance to pests and diseases, improve tillering and shoot and root dry matter production, increase the number of filled grains and grain weight, reduce the concentration of environmental pollutants in rice grain, reduce Na^+ concentration and increase availability of K^+ in saline soils. Comparing rice yields between plots applied with ample amount of N, P, and K (NPK) and plots that received N and P but without K in a long-term experiment different Asian country showed differences in short- and long-term yield responses to fertilizer K among sites. Yield responses to K application were generally small at start, but developed within a few seasons except for the site in Vietnam, where annual flooding supplies a large K load through sedimentation. This finding highlights the need for K application in rice not only to increase yield but also to prevent soil K mining to maintain soil productivity and prevent yield loss.

Zayed *et al.* (2007) studied aiming to investigate the effect of various potassium rates; 0, 24, 48 and 72 Kg K_2O /ha, on growth, sodium, potassium leaf content and their ratio at heading, grain yield and yield components of three hybrids: SK2034H, SK2046H and SK2058H and three varieties; Giza 177, Giza 178 and Sakha 104. The economic values were also estimated. The experimental soil was clayey with salinity levels of 8.5 and 8.7 dS/m in the first and second seasons, respectively. Increasing potassium rate significantly improved all studied traits leading to high grain yield. Furthermore, potassium succeeded to reduce Na^+, lower Na^+/K^+ ratio and raised K^+ resulted in considerable salinity withstanding. The hybrids of SK2034H and SK2046H as well as the salt sensitive rice variety Giza 177 were the most responsive genotypes for potassium fertilizer up to 72 kg K_2O /ha. Consequently, the economic estimates SK2034H had the higher net return and the high potassium level of 72 kg K_2O /ha gave the highest values of economic parameters under the tested saline soil conditions.

Prajapati and Modi (2012) observed the importance of potassium as a key plant nutrient and problems associated with excess and/or deficiencies of potassium in the plant. The availability of potassium to the plant is highly variable, due to complex soil dynamics, which are strongly influenced by root–soil interactions. But it improves nitrogen use efficiency. As we know, nitrogen is directly related to yield. However, if potassium is the limiting nutrient, forage production will decrease. It has re-confirmed the subtle role of potassium in the modulation of plant stomata apertures; by inference, the latter would be linked to potassium deficiency in plants. If potassium is deficient for a plant, it probably activates a signaling mechanism which leads to the translocation of mobile K^+ ions from old to new leaves to support stomata aperture osmo-modulation in the latter.

Experiment 3: Improving quality and shelf life of carrots by applying Potassium in soil.

2.3.1 Effect of potassium on quality and shelf life of carrot

Pekarskas and Bartaseviciene (2007) an experiment was conducted in Lighuania, during 2001-04, to determine the effect of different potassium fertilizer forms on ecologically cultivated carrot yield and quality. Treatment with potassium sulfate increased the total harvest of carrots while the marketable harvest of carrot also increased regardless of the potassium fertilizer form. Potassium fertilizer forms did not have substantial influence on the marketable harvest of carrots. Potassium magnesium increased the content of carotene in carrots significantly compared with potassium chloride fertilizer application.

Hochmuth *et al*. (2006) conducted Potassium (K) is required for successful carrot (*Daucus carota*) production on sandy soils US, Soil test methods for K in carrot production have not been rigorously validated. Excessive fertilization sometimes is practiced by carrot growers to compensate for potential losses of K from leaching and because some growers believe that high rated of fertilization may improve vegetable quality. Carrots were grown in three plantings during the winter of 1994-95 in Gainesville, Fa. To test the effect of K fertilization on carrot yield and quality on a sandy soil testing medium (38 ppm) in Mehlich-1 soil test K. Large-size carrot yield was increased linearly with K fertilization. Yield of U>S. No.1 grade carrots and total marketable carrots were not affected by K fertilization. K fertilizer was no required on this soil even though the University Florida Cooperative Extension Service Recommendation was 84 lb/c acre K. Neither soluble sugar nor carotenoid concentrations in carrots roots were affected by K fertilization. The current K recommendation for carrot grown on sandy soils testing 38 ppm Mehlich-1 K could be reduced and still maintain maximum carrot yield and root quality.

Kancheva (2004) cv. Nantski were supplied with 0, 8, 16 and 24 kg N, P and K/ha in a field experiment conducted in Bulgaria. Results are present on the optimum combinations of fertilizer in Bulgaria. Results are presented on the optimum combinations of fertilizers that will give high carrot yield and quality for processing and direct consumption.

Haworth and Cleaver (1963) studied carrot seedlings from FYM-treated plots on the field experiments at Welles Bourne have been shown to contain more potassium than those from plots which had received only mineral fertilizers including potassium sulphate. It had already been found that the seedlings on the former plots grew more rapidly than those on the latter. In sand culture in the glasshouse, the dry weight of carrot seedlings, ten days after the opening of the cotyledons, increased progressively as the amount of potassium in the nutrient medium and in the aerial parts of the plants increased; the rates of growth and of potassium uptake were found to be similar to those recorded for seedlings grown on the FYM-treated soil. It is concluded that the greater uptake of potassium by seedlings on the FYM-treated plots was largely responsible for their more rapid growth.

Selvi *et al.* (2005) a field study was conducted in India to investigate the effects of different N, P and K levels on carrot. Difference combinations of N, P and K at 100, 135 and 170 kg/ha were used. Full rates of P and K and half rate of N were applied at sowing. The remaining N was applied at 30 days after sowing. The highest yield (21.21 t/ha) was obtained under N, P, K rate of 135, 135,170, followed by 20.25 and 20.21 t/ha obtained from treatments with 170,100,170 and 17,135,170 kg/ha, respectively. A rate of 170, 170, 170 kg/ha did not significantly increase the yield which was low at 18.67 t/ha. Total N content was in the range 1.62-1.98%. N at 135 kg/ha resulted in high total N values (1.90-198%), while N at 170 kg/ha resulted in higher total N values (1.80-1.86%).

Zalewska (2005) a pot experiment was carried out to study the effect of various Ca, Mg, K and H saturations of soil CEC on the yield mineral composition of carrot. A decrease in Kg saturations of CEC to the level approximately 5.7% and simultaneous increase in the saturation of K to the level 13.5% resulted in a significant decrease in carrot yield. A decrease in K saturation of CEC below 5% also caused significant decrease in the yield of carrot roots. An increase in K saturation of CEC from 2.3 to 13% and a simultaneous decrease in Mg saturation from 13.3 to 4.7% caused an increase an in the concentration and uptake of potassium and a decrease in the uptake and content of magnesium in carrot roots and leaves. The result was that the value of K: (Ca= Mg) ratio in carrot roots increased from 0.96 to 2.68 mol.

Kadar (2004) results are presented of experiment conducted in Budapest, Hungary, to the study the effects of N, P and K fertilizers (alone and in combination) on the development, were infestation and yield of carrot cv. Vorosoriasan on the mineral composition of the foliage and roots.

Sady *et al.* (2004) during 1999-2001, investigations concerning the effects of N, P, K, Ca and Mg fertilizer application on the bioaccumulation of cadmium in carrot roots grown two different soils were carried out. The level of nitrate accumulation in carrot roots depended more on the soil (organic matter content) an on the climate conditions than on the fertilizer application factors. Bioaccumulation of cadmium in carrot roots depended both on the soil properties and on the applied fertilizers. Accumulation of cadmium by the plants was significantly limited in the case of calcium and magnesium nutrition, while increase in the case of calcium and magnesium nutrition, while increase in this compound was observed when NPK as well as the individual application of these nutrients were used. The higher cadmium content within the root tissue was observed in the treatment with higher cadmium level in the soil.

Feller *et al.* (2003) new data are presented from farm nutrients measurements during 1999-2001 in spring onions, bunching carrots, Japanese radish, dill, lambs lettuce, rocket salad, celeriac and celery. The average removal of nutrients by harvesting are tabulated for N, P, K and Mg. Nitrogen demand and the minimum nitrogen target value in kg/ha are compared with data published in 2001. Data are within a 10% variation range, however Japanese radish an celery had higher demands due to strong vegetative growth. The highest N demand was found in celery (270 kg N/ha), followed by Japanese radish (245 kg N/ha), rocket salad (100 kg N/ha) and lambs lettuce (38 kg N/ha). For rocket salad, nitrogen uptake curves modeled and measured the uptake by 40% for June-sown plants.

Salo *et al.* (1998) fustigations were compared to broadcast application of solid NPK fertilizer with cabbage (cv. Castello), carrot (cv. Panther) and onion (cv. Sturon). In the broadcast application, P and K were given as a single application in spring and N was spit according to the existing recommendations. In the fustigation applications, nutrient were given according to the expected nutrients uptake were monitored by monthly sampling. In 1998, growing season was expected. However, leaching seemed to have no impact in the sandy experiment soils, as broadcast application resulted in good growth of cabbage and onion. In 1999, natural rainfall was low and irrigation was applied according to tension meter measurements. Treatment did not affect carrot and onion growth, but cabbage growth and nutrients uptake were still decreased by fustigation towards the middle of growing period. At harvest, cabbage yields and nutrients uptakes were similar between the treatments. Cabbage yields averaged to over 90 t/ha in both years. At harvest, total nutrient uptakes were 213-243 kg N/ha, 36-40 kg P/ha and 302-345 kg k/ha. Carrot yielded according to the samplings close to 90 t/ha and nutrient uptake in roots and leaves was 180-190 kg N/ha, 23-30 P/ha and 325-444 kg K/ha. Onion yielded 40-50 t/ha, with uptakes of 117-166 kg N/ha, 18-28 kg P/ha and 117-136 kg K/ha. Fertilizer application did not increase nutrient use efficiency in these experimental conditions. Soil was not prone to leaching and adequate moisture in rooting layer created good conditions for nutrient uptake throughout the season in all treatments.

Salo *et al.* (1998) data on soil analyses, fertilizer use and yields were collected from carrot and pea producers converting to integrated production in 1997, to identity changes in fertilizer practice and effects on yield. On carrot field, the average total N rate was 80 kg/ha. Corresponding P rates averaged 35 kg/ha and K rates 131 kg/ha. The P rate was reduced when soil P analyses were high, but K rate was not adjusted for soil K. The resulting changes in N,P and K rates had not influence on the carrot yield, which averaged 49 t/ha (close to the national average). On pea fields, the average N rate was 42 kg/ha, with rates reduced where soil organic matter content was high. P rates averaged 16 kg/ha and K rates and K rates 52 kg/ha. There was no evidence that these fertilizer rates were adjusted for soils P or K content. Changes in N, P and K fertilizer practice again had no influence on the yield, which averaged 5.4 t/ha. The data showed that as a rule, farmers followed fertilizer recommendations. Nitrogen rates were adjusted according to the estimated yield, but results of soil analyses were often not used in fertilization planning. Yield data showed that the existing fertilizer recommendations are sufficient to achieve average yields in Finland, and that the recommendations rates could be reduced even further.

Lazar and Dumitras (1997) an experiment was conducted in Romania, during 1995-97 on carrot cultivars Nantes and Chantenay to study the effect of sowing date and fertilizer application on the yield and quality of carrot roots. The treatments comprised: late March and early-June sowing, 110 kg KCI + 150 kg NH_4NO_3/ha and 150 kg KNO_3 + 100 kg NH_4NO_3/ha. Late March sown Chantenay gave the best yield. However, Nantes particularly those sown in early-June, showed higher quality than Chantenay. The application of KNO_3 increased the yield and quality of carrot roots.

Singh (1996) the effect of N (50, 100 or 150 kg/ha) and K (20, 40, 60 or 80 kg/ha) on carrot (cv. Pusakesar) seed yield were investigated in the field during winter seasons of 1992-93 and 1993-94. Pant height, number of umbels/plants and seed yield increased with increasing rates of N.

Maximum plant height (mean of 148.95 cm), number of umbels/plant (46.27) and seed yield (9.84 q/ha) were recorded following application of 150 kg N/ha. The number of umbels/plant and seed yield also increasing rates of K, the highest seed yield (mean of9.35 q/ha) was observed at the highest rate of K.

Sharangi and Paria (1996) conducted a field trial on a sandy loam soil during the winter seasons of 1992-93. Carrot received N fertilizer at 0, 50, 70 or 80 kg/ha combination with K fertilizer at 0, 40, 50 or 60 kg/ha. Application of 80 kg/ha N/ha + 50 kg K/ha produced the longest, widest and heaviest roots.

Konopinski (1995) carried out field trials near Lubin, Poland, with carrot cv. Perfection. The plants received N:P:K at150:150:300 kg/ha (control) or Super Fertilizer of French manufacture containing 11% organic matter, 14% Ca, 3.5% Mg, 4% P2O5, 2.5% SO3 plus all essential microelements. Super Fertilizer was applied at 50 or 100 kg/ha. Using the 100 kg/ha Using the 100 kg/ha rate gave the best yield increase in carrot viz, 70 and 30% over the control respectively. Crops quality was also best in the variant.

Sharangi and Paria (1995) carried out an experiment where carrots (cv. PusaKesar) were grown in the winter seasons of 1992 on a sandy loam soil with N fertilizer at 0,50,70 or 80 kg/ha and K at 0,40,50 or 60 kg k_20 /ha. P was applied at 60 kg/ha. The crop was harvested 120 days after sowing.

Shoot growth, root diameter, carotene and total sugar contents increased with increasing rate of N. Root yield was also highest with the highest N rate (22.08 t/ha). With K application, most parameters increased with up to 50 kg/ha, then remained steady or declined with 60 kg/ha, although yield increased further with 60 kg/ha (19.66 t/ha). An interactive effect between N and K was found for plant height, root length, root diameter and root sugar content.

Kadi *et al.* (1994) carried out a trial at the Bajo Saco experimental station in Venezuela with carrot cv. Super Fluke. Seeds were sown on 22 Feb on an Orthotics TropudultsUltisol soil which 0-200 kg P_2O_5, 0-300 kg K_2O and 0-40 kg poultry manure/ha had been applied. Thinning was carried out on 15-18 April so that the distance between plants was3, 6, 9, 12 or15 cm. The highest yield at harvest (95.6 t/ha) was obtained with 150 kg P_2O_5 + 225 kg K_2O) + 10 t poultry manure/ha and a distance of 123 cm between plants, but the results were not statistically significant.

Roa (1994) conducted a field experiment on red sandy loam soil, the effects of K at 0, 50, 100, 150 and 200 kg K_2O/ha as KCI or K_2SO_4 on growth yield and quality of carrot. Mean root weight and yield were highs at 50kg K_2O/ha. Carotene content was increased by K application.

Balooch *et al.* (1993) carried out a field trial during 1988-89. Tandojam carrots were grown from seed in seedbed to which 75 and 100 kg $P_2O_5$and 75, 100 or 125 kg K_2O/ha had been applied All plots also received 100 kg N in 3 split application during seed beds preparation. They observed that root yield was highest at the highest NPK rate. This due to increase root size and weight.

Abo-Sedera and Eid (1992) stated in a field trail during the winter season of 1989/90 and 1990/91. Carrot cv. Red Cored Chantenay plants on a clay loam soil was supplied with N and K2O at 30 and 24, 45 and 48 or 60, 72 kg/feddan respectively in 2 equal application, 4 and 8 weeks after sowing. Overall, the best results, in terms of vegetative growth, yield and quality, weight were obtained with 60 kg N + 72 kg K_2O feddan.

Pill and Evans (1991) incorporation of 15 g of 9:8: 12.5 N: P: K fertilizer of fluid drilling get increased shoot fresh weight compared with untreated, primed or hydrated seeds under greenhouse condition. When these same treatments were applied under field condition, 15 g of 9: 8:12.5 N: P: K fertilizer/litter increased economic root fresh weight but the seed treatment had liter effect.

Grigrov (1990) on medium or heavy loamy soil in the between the rivers Volga and Don, the soil moisture content during germination to start of root development should be maintained at not less than 80-85 and thereafter at 70%. For this, 15 irrigation application (4400 m water/ha) were required in dry years and 8 applying N: P: K at 60:130: 20 kg/ha and 40-50 t/ha yield of ecologically clean produce could be expected.

Tremblay and Parent (1989) a survey of carrot and onion production by various growers on Quebec histosols south Montreal in 1986 and 1987 showed that NPK fertilization in 1987 was not correlated with yield in that year, but that there was a correlation between yield in 1987 and NPK application in 1986 for carrots only. This indicates that the residual effect of previous crops are important in carrot production, and that fertilization strategy should take the crop rotation into account.

Sarker (1999) conducted an experiment with different levels of nitrogen, phosphorus and potassium on yield and components of carrot and reported that the highest yield of 31.99 t/ha of carrot was obtained from the plants fertilized with the highest of nitrogen (120kg N/ha). The highest yield of 34.27 t/ha was recorded when nitrogen and potash each at 120 kg/ha were applied. Application of nitrogen significantly affected the root length and individual root weight. K and significant effect on root diameter and fresh weight and had no significant effect on root length.

In a two-years trial Evers (1988) found that the shoots reached their maximum weight 3 months after sowing, whereas root growth considerably more during both the 3 and 4 months. The roots and shoot DM were positively correlated and the yield was also increased by the application of K and N.

Bruckner (1986) conducted an experiment over3 years and reported that increasing the N supply (0-200 kg N/ha) produced a relatively small increases in yield. N at 100 kg/ha gave the best yield without increasing the content of carrots. Cultivars Flakkeer RZ and FalkkerKaraf had a high uptake of K_2O (242.8-326.6 kg/ha) and low uptake of P_2O_5 (62.3-64.4 Kg/ha), Ca (39.1-58.0 kg/ha) and Mg (19.0-26.98 kg/ha).

Jacobson *et al.* (1980) reported that the effect of fertilizer was studied in a field trial involving N, P, K at 16-5-12 or 14-4-17 with N at 60,120,180 and 240 kg/ha. Yield was not significantly affected, but the increase of cavity spot was least at the lowest rate N and at all rates of N was less with the formulation containing the lower level of K.

Krarup *et al.* (1984) conducted an experiment where chant nay carrot was fertilized with K_2O (0,100 0r 200 units/ha). There was no difference in total yield with the medium and high K_2O levels. K_2O content regards from 0.67 to 0.83% in roots and from 0.54 to 0.76% in leaves. Nutrient extraction by the whole plant (calculated on the basis of yield and content) varied with the level of application; from 63.35 to 94.33 kg/ha for K_2O. Leaf and root K_2O content and the level of K_2O extraction were lower than expected. Probably due to the characteristics of the soil, which deficient in K.

Farazi (1993) while conducting as experiment on spacing and application of fertilizer concluded that the highest yield of carrot (454 t/ha) was obtained from the crop fertilized with the highest of N (112 kg N/ha), and potash had no significant effect on then yield of carrot. Both nitrogen and potash had significant effect of diameter of root, but little effect on the length of root. The weight of leaves per plant was increased with the increasing level of nitrogen and potash and no considerable effect on the weight of leaves per plant.

Polach (1982) conducted a 4 years fertilizer trial with the carrot cv. Nantes, grown on a soil with adequate phosphorus and medium to low potassium content Nitrogen at 0-180 kg/ha and potash at 0-196 kg/ha were applied in 12 difference treatments. Basal nitrogen application at 60 kg/ha and basal potash 151.2 kg/ha gave the best yield and quality of carrot.

Singh and Singh (2000) conducted the effects of N (50, 100 or 150 kg/ha) and K (20, 40, 60 or 80 kg/ha) on carrot (cv. Pusakesar) seed yield were investigated in the field during winter seasons of 1992-93 an 1993-94. Plant height (46.27 cm) and seed yield (9.84 q/ha) were recorded following application of 150kg N/ha. The number of umbels/plant and seed yield also increased with increasing rates of K; the highest seed yield (mean of 9.35 q/ha) was observed at the highest rate of K.

Jacobson *et al.* (1980) mentioned that black polythene sheets placed on the soil during the hot season increased soil temperature by 4-12^{0}C in the upper 5 cm layer and thereby controlled the weed in the mulched plots where carrot grew normally.

The above literature showed the importance of Potassium in case of carrot production. Hence the research work has been under taken to examine the influence of and potassium on the growth yield of carrot.

CHAPTER III

Materials and Methods

Conducting a research study, methodology is one of the prime considerations for generating valid and reliable findings. Appropriate methodology enables the researchers to collect valid and reliable information and to analyze the information properly in order to arrive at correct conclusions. However, the methods and operational procedures followed in conducting three separate experiments have been described in the subsequent sections of this chapter.

3.1 Experimental plan:

Three separate experiments were carried out during the period from October 2016 to April 2018. These were:

Experiment 1: Effect of potassium on the growth and yield of wheat under water stress condition

Experiment 2: Integrated nutrient management for boro rice to investigate potassium balance in soil.

Experiment 3: Improving quality and shelf life of carrots by applying potassium in Soil.

3.2 Experimental site and duration:

The first experiment was conducted for wheat during October 2016 to March 2017 and second experiment was conducted for rice during December 2017 to April 2018 and third experiment was conducted for carrot during January 2018 to March 2018 at research field of Sher-e-Bangla Agricultural University, Dhaka.

3.3 Site description

Geographical location: The experimental field was situated at 23°77°N latitude and 90°33°E longitude at an altitude of 8.6 meter above the sea level.

3.3.1 Agro ecological zone (AEZ):

The experimental field belongs to the agro ecological zone of the Madhupur Tract, AEZ 28. The region was complex relief and soils developed over the Madhupur clay, where floodplain sediments buried the dissected edges of the Madhupur Tract leaving small hill tracks of red soils as islands surrounded by floodplain.

3.3.2 Soil:

The soil of the experimental site belongs to Tejgaon series under the general soil type,” Deep Red Brown Terrace” soils. Top soils were clay loam in texture, olive gray with common fine to medium distinct dark yellowish-brown mottles. The experimental area was flat having available irrigation and drainage system and above flood level. Soil samples from 0-15 cm depths were collected from experimental field. The initial macro nutrients and chemical properties of three experimental fields were shown Table 3.1 and Table 3.2.

Table 3.1: Morphological characteristics of the experimental field

Physiological properties	Characteristics
Location	Sher-e-Bangla Agricultural University farm, Dhaka, Bangladesh
AEZ	Madhupur Tract
General soil type	Deep Red Brown Terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained

Table 3.2: Physical and chemical properties of the initial soil sample of research fields

Soil analysis	Soil of Experiment- 1 (Wheat)	Soil of Experiment- 2 (Rice)	Soil of Experiment- 3 (Carrot)
pH	5.8	6.2	5.6
Organic Carbon	0.62	0.66	0.56
Total N (%)	0.06	0.06	0.08
Available P (ppm)	15.75	20.32	22.64
Exchangeable K (meq 100^{-1}g soil)	0.12	0.16	0.14
Available S (ppm)	13.30	12.40	12.29

3.3.3 Climate:

The area has sub-tropical climate, characterized scanty rainfall associated with moderately low temperature during the robi season (October- March).

3.4 Experimental materials, design and crop growing

3.4.1 Experiment 1: Effect of potassium on the growth and yield of wheat under water stress condition.

BARI gom26 was used in this experiment as test crop for integrated nutrient management especially potassium balance in soil with control following a two-factor experiment in Split plot design with three replications.

3.4.1.1 Factor A: Irrigation level

I_0= control (normal irrigations)

I_1= Water stress at vegetative stage,

I_2= Water stress at flower initiation stage,

I_3= Water stress at milking stages.

3.4.1.2 Factor B: Different doses of potassium

K_0= 0 kg K/ha ,K_1= 60 kg K//ha, K_2= 90 kg K/ha, K_3= 120 kg K/ha

The following recommended doses of fertilizers were used in the experiments

Sl No.	Name of nutrient	Name of fertilizer & composition	Dosage (kg ha^{-1})
i.	Nitrogen, N	Urea, 46% N	140.0
ii.	Phosphorus, P	TSP, 20.0% P	30.0
iii.	Sulphur, S	Gypsum, 18.0% S	12.0
iv.	Zinc, Zn	Zinc Sulphate, 36.0% Zn	2.5
v.	Boron, B	Boric Acid, 17.0% B	1.0

Source: According to Fertilizer Recommended Guide 2012, BARC

There were 16 treatment combinations (4 levels of irrigation X 4 level of K doses) which were as follows:

1. $I_0 \times K_0$ = control (normal irrigations) 0 kg K /ha
2. $I_0 \times K_1$= control (normal irrigations) 60 kg K/ha
3. $I_0 \times K_2$= control (normal irrigations) 90 kg K/ha
4. $I_0 \times K_3$= control (normal irrigations) 120 kg K/ha
5. $I_1 \times K_0$= Water stress at vegetative stage with 0 kg K/ha
6. $I_1 \times K_1$= Water stress at vegetative stage with 60 kg K/ha
7. $I_1 \times K_2$= Water stress at vegetative stage with 90 kg K/ha
8. $I_1 \times K_3$= Water stress at vegetative stage with 120 kg K/ha
9. $I_2 \times K_0$= Water stress at flower initiation stage with 0 kg K/ha
10. $I_2 \times K_1$= Water stress at flower initiation stage with 60 kg K/ha
11. $I_2 \times K_2$= Water stress at flower initiation stage with 90 kg K/ha
12. $I_2 \times K_3$= Water stress at flower initiation stage with 120 kg K/ha
13. $I_3 \times K_0$= Water stress at milking stages with 0 kg K/ha
14. $I_3 \times K_1$= Water stress at milking stages with 60 kg K/ha
15. $I_3 \times K_2$= Water stress at milking stages with 90 kg K/ha
16. $I_3 \times K_3$= Water stress at milking stages with 120 kg K/ha

3.4.1.3 Experimental design

BARI gom26 cultivar was used in this experiment and the experiment was laid out in a Split Plot Design with three replications. Each block was sub-divided into sixteen-unit plots. The treatments were randomly distributed to the unit plots in each block. The total number of plots 48 was (16 X 3). The unit plot size was 1.5 m to 3 m. Block to block distance was 0.75 m and plot to plot distance was 0.5 m.

3.4.1.4 Seed collection

Healthy and vigor seeds of BARI gom26 were collected from Wheat Research Center of Bangladesh Agricultural Research Institute, Joydebpur, Gazipur.

3.4.1.5 Preparation of land

The experimental field was prepared on October 15, 2016 with the help of tractor after that the land was fully irrigated and prepared by three successive ploughing and cross ploughing with a tractor drawn plough and subsequently leveled by laddering. All weed and other plant residues of previous crop were removed from the field. Individual plots were cleaned and finally leveled.

3.4.1.6 Sowing of wheat seed

BARI gom26 was showing in the experiment field on 15 November 2016 keeping row to row distance 20 cm.

3.4.1.7 Application of fertilizers and irrigations

All TSP, MoP, gypsum, zinc sulphate and boric acid fertilizers were applied as basal dose in the experiment. The recommended dose of nitrogen was 140 kg ha^{-1}. Nitrogen was applied in three equal splits. The first spilt was applied as basal dose in the preparation of experimental layout. The second spilt was applied tillering stage and third split was applied grain filling stage. Different doses of potassium were applied with the combinations of recommended fertilizers and irrigations in the experimental plots as per treatments.

3.7.1.8 Intercultural operations

Thinning and gap filling

After one week of direct seed sowing thinning was done to maintain the constant population number. Gap filling was done whenever it was necessary.

Weeding

The crop was infested with some weeds during the early stage of crop establishment. Two hand weeding were done for every method, first weeding was done at 15 days after seed sowing followed by second weeding at 15 days after first weeding.

Application of Irrigation

The first irrigation was applied in the land preparation in all plots. From second irrigation to final irrigation water was applied to the research plots as per treatments.

Plant protection measures

Wilting was occurred at seedling stages to some extent which was treated by two time applying Redomil Gold. Crop was protected from birds and rats during the grain filling period. Field trap and foxtoxin poisonous bait was used to control the rat. For controlling the birds watching was done properly, especially during morning and afternoon.

3.4.1.9 Harvesting

The crops were harvested at maturity on 20 March 2017. The harvested spikes were threshed plot wise. Dry weight for both seed and straw were also recorded.

3.4.1.10 Collection of data at harvest

Plants from one square meter were randomly selected from each plot to record the yield contributing characters like plant height (cm), number of tillers per plants, effective tillers per plants, non-effective tillers per plants, length of flag leaf, ear length (cm), number of spikelet per spike (cm), fertile floret per spikelets, number of filled grain per spike, number of unfilled grain per spike, total grain per spike, weight of 1000 seeds. Seed and straw yields were recorded plot wise and expressed at t/ha on sun dry basis.

3.4.1.11 Collection of data

The following data on growth and yield contributing characteristics of wheat were recorded:

A. Crop growth parameters

i. Plant height

ii. Number of tillers per plants

iii. Effective tillers per plants

iv. Non effective tillers per plants

v. Length of flag leaf

B. Yield contributing characters

vi. Ear length (cm)

vii. Number of spikelets per spike (cm)

viii. Fertile floret per spike

ix. Number of filled grains per spike

x. Number of unfilled grains per spike

xi. Total grains per spike

xii. Weight of 1000 grains

C. Yield parameters

xiii. Grain yield (t ha^{-1})

xiv. Straw yield (t ha^{-1})

xv. Biological yield t ha^{-1})

xvi. Harvest index (%)

Plant height (cm)

The plant height was measured (cm) from the ground level to the tip of panicle. Five plants were randomly selected and plant heights were observed from per plot and data were average from each plot.

Effective tillers per plant

The number of panicle bearing tillers of each plant was counted manually and number of effective tillers of five plants were counted and done average for each plot.

Non effective tillers per plants

Numbers of non-effective tillers per plants were counted manually from per plot and mean data were used.

Length of flag leaf

Length of the flag leaf was measured manually from the base up to the tip of the flag leaf.

Ear length

Measurement was taken from base of panicle to apex of each panicle. Each observation was an average of five panicles.

Number of spikelets per spike

The total number of spikelets spike^{-1} was counted as the number of spikelets from 10 randomly selected spikes from each plot and average value was recorded.

Fertile floret per spikelets

The numbers of fertile florets were counted from randomly selected spikelets. Ten plants of each plot.

Number of filled grains per spike

The total number of filled grains per spike was counted as the number of filled grains from randomly selected spikes from each plot and average value was recorded. Ten plants of each plot.

Number of unfilled grains per spike

The total number of unfilled grains spike^{-1} was counted as the number of unfilled grains from randomly selected spikes from each plot and average value was recorded. Ten plants of each plot.

Total grains per spike

The total number of grains spike^{-1} was counted by adding the number of filled and unfilled grains from randomly selected spike from each plot and average value was recorded. Five plants of each plot.

Weight of 1000 grains

One thousand grains were counted randomly from the total cleaned harvested grains of each individual plot and then weighed and recorded which was expressed in gram.

Grain yield

Grains obtained from each unit plot were sun-dried and weighed carefully. The dry weight of grains of central $1m^2$ area and five sample plants were added to the respective grain yield per square meter and converted to t ha^{-1}.

Straw yield

Straw obtained from each unit plot were sun-dried and weighed carefully. The dry weight of straw of central 1 m^2 area and five sample plants were added to the respective straw yield m^{-2} and finally converted to t ha^{-1}.

Biological yield

Grain yield and straw yield together were regarded as biological yield. The biological yield was calculated with the following formula:

Biological yield = Grain yield + Straw yield.

Harvest index

Harvest index was calculated from the grain and straw yield of rice for each plot and expressed in percentage.

$$HI = \frac{\text{Economic yield (grain weight)}}{\text{Biological yield (Total dry weight)}} \times 100$$

3.4.2 Experiment 2. Integrated nutrient management for boro rice to investigate potassium balance in soil

BRRI dhan28 were used in this experiment for integrated nutrient management especially potassium balance in soil with control in Randomized Complete Block design with three replications.

3.4.2.1 Planting Material: Variety (BRRI dhan28)

BRRI dhan28 was developed Bangladesh Rice Research Institute, Gazipur Bangladesh in 1994. The main characteristics are plant height 90 cm, clean rice, medium slender and white. Life time 140 days. Planting season boro, mid to late November. Harvesting time is early to mid-April. Average yield is 6.0 t/ha.

Treatments:

T_1 = Control (no fertilizer)

T_2 = Fertilizer recommended dose for BRRI dhan28. (FRD) $N_{120}P_{18}K_{75}S_{13}Zn_{1.5}$

T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg /ha K) from MoP

T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg/ha K) from MoP

T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg/ha K) from MoP

T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg/ha K) from MoP

T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg/ha K) from MoP

T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg/ha K) from MoP

T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg/ha K) from MoP

T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg/ha K) from MoP

T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg/ha K) from MoP

3.4.2.2 The following recommended doses of fertilizers were used in the experiments

Sl No.	Name of nutrient	Name of fertilizer and composition	Dosage (kg ha^{-1})
i.	Nitrogen N	Urea, 46% N	120.0
ii.	Phosphorus, P	TSP, 20.0% P	18.0
iii.	Potassium, K	MoP, 50.0% K	75.0
iv.	Sulphur, S	Gypsum, 18.0% S	13.0
v.	Zinc, Zn	Zinc Sulphate, 36.0% Zn	1.5

Nutrient content of different organic manure

Nutrient	Cowdung	Poultry Liter	Vermicompost
N	1 %	1.6 %	0.75 %
P	0.6 %	1.5%	1 %
K	1.5 %	0.85%	1%
S	0.3%	0.75%	0.5%

(Source Fertilizer Recommendation Guide 2012)

3.4.2.3 Experimental design

The experiment was laid out in an RCBD with three replications. Each block was subdivided into eleven-unit plots. The treatments were randomly distributed to the unit plots in each block. The total number of plots was 33 (11 X 3). The unit plot size was 2 m to 2 m. Block to block distance was 1 m and plot to plot distance was 0.5 m.

3.4.2.4 Collection of seed

Healthy and vigor seeds of BRRI dhan28 were collected from Genetics and Plant Breeding Division of Bangladesh Rice Research Institute, Joydebpur, Gazipur.

3.4.2.5 Preparation of seedling nursery and seed sowing

A piece of high land was selected in the SAU Agricultural farm, Dhaka for raising seedlings. The land was puddled well with country plough followed by cleaning and leveling with ladder. Sprouted seeds were sown in the nursery bed on 19 November 2017. Proper care was taken to raise the seedlings in the nursery bed. Weeds were removed and irrigation was given in the seed bed as and when necessary.

3.4.2.6 Preparation of land

The experimental field was first opened on December 22, 2017 with the help of a tractor drawn disk plough, later on December 23, 2017 the land was irrigated and prepared by three successive ploughings and cross ploughings with a tractor drawn plough and subsequently leveled by laddering. All weed and other plant residues of previous crop were removed from the field. Immediately after final land preparation, the field layout was made on January 03, 2018 according to experimental specification. Individual plots were cleaned and finally leveled with the help of wooden plank so that no water pocket could remain in the puddled field.

3.4.2.7 Uprooting of seedlings

The seedling bed was made wet by application of water on the previous day of uprooting the seedlings. The seedlings were uprooted carefully without causing any injury to the roots. The uprooted seedlings were kept on soft mud under shade.

3.4.2.8 Transplanting of seedlings

On 03 January 2018, 45 days old seedlings were transplanted in the experiment field keeping plant to plant distance 15 cm and row to row distance 25 cm. Gap filling was made after 7 days of transplanting to maintain proper treatment and similar plant population density for each plot.

3.4.2.9 Application of fertilizers

The full of triple super phosphate (TSP), muriate of potash (MoP), gypsum and zinc fertilizer were applied in the experimental plot @ P_{18}, K_{75}, S_{13}, $Zn_{1.5}$ kg ha^{-1} respectively as basal dose in the experimental plots except control plot along with the cowdung, poultry litter and vermicompost. The recommended dose of N was 120 kg ha^{-1}. N was applied as per treatment in three equal splits. The first split was applied after 15 days of transplanting, the second split was applied after 35 days of transplanting i.e. at active vegetative stage and the third split was applied after 60 days of transplanting i.e. at panicle initiation stage.

3.4.2.10 Intercultural operation

Gap filling

After transplanting the seedlings of the research field, gap filling was done whenever it was necessary. Within week, seedlings were transplanted to the gap to maintain the constant population number.

Weeding

The crop was infested with some weeds due in the early stage of crop establishment. To hand weeding were done for every method, first weeding was done at 15 days after seedlings transplanted followed by second weeding at 15 days after first weeding.

Application of irrigation water

Irrigation water was added to each plot whenever necessary. Partial amount of water was applied to keep the soil moist, and it was even allowed to dry out for 2 to 4 days during tillering. This was done to keep the soil well aerated, to allow better root growth. From panicle initiation (PI) to hard dough stage, a thin layer of water (2 to 3 cm) was kept on the plots. Again water was drained from the plots during ripening stage.

Plant protection measures

Plants were infested with rice stem borer (*Scirphophaga incertolus*) and leaf hopper (*Nephotettix nigropictus*) to some extend which were successfully controlled by applying diazinon @ 10 ml/ 10 liter of water for 5 decimal lands on February 7, 2018 and by ripcord @ 10 ml/ 10 liter of water for 5 decimal lands on February 25 and March 5, 2018. Crop was protected from birds and rates during the grain filling period. Field trap and phostoxin poisonous bait was used to control the rate. For controlling the birds watching was done properly, especially during morning and afternoon.

3.4.2.11 Harvesting

The crop was harvested at maturity stage on 15 April 2018. The harvested crop was collected plot-wise. Grain and straw yields were recorded separately plot-wise and moisture percentage was calculated after some time. Dry weight for both grain and straw also recorded.

3.4.2.12 Data collection at harvest

Plants from one square meter were randomly selected from each plot to record the yield contributing characters like plant height (cm), number of total tillers per plants, effective tillers per plants, non-effective tillers per plants, length of flag leaf, Ear length (cm), panicle length, number of grains per panicle, number of total grain, number of filled grain, number of unfilled grain, weight of 1000 grain weight (g) and grain yield (t ha^{-1}). The selected hills were collected before harvesting. Grain and straw yields were recorded plot-wise and expressed at t ha^{-1} on sundry basis.

3.4.2.13 Collection of data

The date on the following growth and yield contributing characters of the crop were recorded:

A. Crop growth related characters

- Plant height (cm)
- Number of effective tillers per plant
- Number of non-effective tillers per plant
- Length of flag leaf

B. Yield contributing characters

- Panicle length (cm)
- Number of total grains per panicle
- Number of filled grains per panicle
- Number of unfilled grains
- 1000 grains weight (g)

C. Yield related characters

- Grain yield (t ha^{-1})
- Straw yield (t ha^{-1})
- Biological yield (t ha^{-1})
- Harvest index (%)

Plant height (cm)

The height of the plant was recorded in centimeter (cm) at harvest. Data were recorded as the average of 5 plants selected at random from the inner rows of each plot. The height was measured from the ground level to the tip of the tiller.

Number of effective tillers per plant

The number of effective tillers per plant of five was counted manually per hill and average data was recorded.

Number of non- effective tillers per plant

The number of non- effective tillers per plant was counted manually per hill and average data was recorded.

Length of panicle

The length of panicle was measured with a meter scale from 5 selected panicles and the average value was recorded.

Filled grains panicle^{-1}

The total number of filled grains was collected randomly from selected 5 plants of a plot on the basis of grain in the spikelet and then average number of filled grains panicle^{-1} was recorded.

Unfilled grains panicle^{-1}

The total number of unfilled grains was collected randomly from selected 5 plants of a plot on the basis of no grain in the spikelet and then average number of unfilled grains panicle^{-1} was recorded.

Grain yield

Grains obtained from each unit plot were sun-dried and weighed carefully. The dry weight of grains of central 1m^2 area and five sample plants were added to the respective grain yield m^{-2} and converted to t ha^{-1}.

Straw yield

Straw obtained from each unit plot were sun-dried and weighed carefully. The dry weight of straw of central 1 square meter area and five sample plants were added to the respective straw yield square meter and finally converted to t ha^{-1}.

Biological yield

Grain yield and straw yield together were regarded as biological yield. The biological yield was calculated with the following formula:

Biological yield = Grain yield + Straw yield.

Harvest index (%): It denotes the ratio of economic yield to biological yield and was calculated with the following formula. (Gardner *et al.*, 1985)

Harvest index was calculated from the grain and straw yield of rice for each plot and expressed in percentage.

$$\text{Harvest index (\%)} = \frac{\text{Economic yield (grain weight)}}{\text{Biological yield (Total dry weight)}} \times 100$$

Where economic yield = Grain yield, and Biological yield = Grain yield + Straw yield

3.4.3 Experiment 3: Improving quality and shelf life of carrots by applying potassium in Soil.

The carrot variety New Kuroda was used in this experiment for observing the improvement of quality and shelf life by applying potassium in soil with control in RCBD with three replications.

3.4.3.1 Recommended doses of fertilizer for carrot other than K

SL no.	Name of nutrients	Name of fertilizer and composition	Optimum dosage (kg ha^{-1})
i.	Nitrogen, N	Urea, 46 % N	124
ii.	Phosphorus, P	TSP, 20.0 % P	40
iii.	Sulphur, S	Gypsum, 18.0 % S	24

3.4.3.2 Variety (New Kuroda)

Treatments:

1. T_1 = 0 kg K/ha
2. T_2 = 20 kg K/ha
3. T_3 = 40 kg K/ha
4. T_4 = 60 kg K/ha
5. T_5 = 80 kg K/ha
6. T_6 = 100 kg K/ha
7. T_7 = 120 kg K/ha
8. T_8 = 140 kg K/ha

3.4.3.3 Experimental design

Carrot variety New Kuroda was used in this experiment and the experiment was laid out in RCBD design with three replications. Each block was subdivided into eight unit plots. The treatments were randomly distributed to the unit plots in each block. The total number of plots was (8 X 3) 24. The unit plot size was 2.5 m to 2 m. Block to block distance was 1 m and plot to plot distance was 0.5 m.

3.4.3.4 Land preparation

The land that was selected to conduct the experiment was opened on October 2017 with the help of a power tiller and then it was kept open to sun for 7 days prior to further ploughing. Afterwards it was prepared by ploughing and cross ploughing followed by laddering. Deep ploughing was done to have a good tilth, which was necessary for getting better yield of this crop. The weeds and stubbles were removed after each laddering. Simultaneously the clods were broken and the soil was made into good tilth.

3.4.3.5 Application of Fertilizers

Eight potassium fertilization rates (0, 20, 40, 60, 80, 100, 120, and 140 kg K) were applied in the plots as per treatment. Potassium treatments in the form of MoP, a rate of 124 kg/ha N and triple super phosphate at the rate of 40 kg/ha P were applied in the field. All of phosphorus, potassium and sulphur; and one third of N fertilizer applied as basal dose during final land preparation. Remaining N fertilizer which ware applied at the 3rd and 5th week after seed sowing.

3.4.3.6 Collection and sowing of seeds

The seeds of carrot cv. "New Kuroda", was used in the experiment. The seeds were in a sealed container, and procured by the Dhaka Seed Store, Dhaka. The seeds were soaked in water for 24 hours and then wrapped with piece of thin cloth. The soaked seeds were then sprayed over polythene sheet for 2 hours to dry out the surface water. This treatment was given to help quick germination of seeds @ 3 kg ha^{-1} were sown is field on November 17, 2017. Small holes of about 1.5 cm depth were made at a distance of 15 cm along the row spaced at a distance of 25 cm, three or four seeds were placed in each hole and covered with loose soil.

3.4.3.7 Intercultural operations

Thinning out

Seedling emergence was completed within ten days and when the attained a height about 20 cm were thinned out two times. First thinning was done after 20 days of sowing, leaving two seedlings in each hill. The second thinning was done ten days after first thinning, keeping only one seedling in each hill.

Weeding

Weeding was done four times in plots to keep plots free from weeds.

Pest management

Mole cricket, field cricket and cutworm attack were the serious problems for carrot cultivation. As a preventive measure against the insect pest, Dursban 20 EC was applied @ 0.2% at 15 days interval for three times starting from 20 days after sowing.

Diseases management

The crop was healthy and disease free and no fungicide were used.

3.4.3.8 Harvesting

The crop was harvested on March 2018 i.e.120 days after sowing (DAS). Harvesting of the crop was done plot wise. It was done by uprooting the plants by hand carefully. The soil and fibrous roots adhering to the conical roots were removed and cleaned.

3.4.3.14 Data collection

Data on the following parameters were recorded from the sample plants during the course of experiment. Five plants were sampled randomly from each unit plot for the collection of data. The whole plot was harvested to record per plot yield. Data were collected on different growth, yield components and yield. The plants in the outer rows and at the extreme end of the middle rows were excluded from the random selection to avoid the border effect. The following observations were made regarding plant growth, yield and yield attributes. The following parameters were recorded:

- Plant height (cm)
- Number of leaves per plant
- Length of leaves
- Fresh weight of leaves per plant (g)
- Length of roots (cm)
- Fresh weight of roots per plant (g)
- Weight of roots with leaves (g)
- Weight of roots without plant (g)
- Yield with leaves per plot (t ha^{-1}))
- Yield without leaves per hectare (t ha^{-1}))

Plant height (cm)

Plant height was measured in centimeter (cm) by a meter scale at 45, 60, 75 and 90 DAS from the point of attachment of the leaves to the root (ground level) up to the tip of the longest leaf. Average data of plant height was recorded from 5 plants per plot.

Number of leaves per plant

Number of leaves per plant of ten random selected hills was counted at 45, 60, 75 and 90 DAS. All the leaves of each plant were counted separately. Only the smallest young leaves at the growing point of the plant were excluded from the counting and the average number was calculated.

Length of leaves

Length of leaves was measured in centimeter (cm) by a meter scale at 45, 60, 75 and 90 DAS from the point of attachment of the leaves to the tip of the longest leaf.

Fresh weight of leaves per plant

Leaves were detached by a sharp knife and fresh weight of the leaves was taken by a triple beam balance at harvest (90 DAS) and was recorded.

Length of root (cm)

The length of the conical roots was measured in cm with the help of a meter scale from the proximal end of the conical root to the last point of the tapered end of the root (distal end) in each treatment.

Diameter of root (cm)

To measure the diameter of the root a slide calipers was used. The diameter of the roots was measured in cm after harvest at the thickened portion of the root.

Fresh weight of root per plant (g)

Underground modified carrot roots of ten selected plants were made detached by a knife from the attachment of the stem and after cleaning the soil and fibrous root fresh weight was taken by the triple beam balance in gram and then the average value was calculated.

Yield of roots with leaves (t/ha)

A balance was used to record the weight of the harvested roots with leaves. The weight of the roots was taken in kilogram (kg) from each unit plot.

Yield of roots without leaves (t/ha)

A balance was used to record the weight of the harvested roots. The weight of the roots was taken in kilogram (kg) from each unit plot.

3.5 Chemical analysis of soil sample

Soil samples were analyzed for both physical and chemical properties in the laboratory of Soil Resource Development Institute (SRDI), Divisional laboratory, Dhaka. The properties studied included pH, organic carbon, total N, available P and exchangeable K. The chemical properties of the initial soil have been presented in Table 3.2. The soil was analyzed by standard methods:

Soil pH

Soil pH was measured with the help of JENWAY 3510 glass electrode pH meter, the soil water ratio being maintained at 1: 25 as described by Page *et al.*, (1982)

Organic carbon

Organic carbon in soil sample was determined by wet oxidation method. The underlying principle was used to oxidize the organic matter with an excess of 1N $K_2Cr_20_7$ in presence of conc. H_2SO_4 and conc. H_3PO_4 and to titrate the excess $K_2Cr_20_7$ solution with 1N $FeSO_4$. To obtain the content of organic matter was calculated by multiplying the percent organic carbon by 1.73 (Van Bemmelen factor) and the result were expressed in percentage (Page *et al.*, 1982).

Total nitrogen (N)

Total N content of soil were determined followed by the Micro Kjeldahl method. One gram of oven dry ground soil sample was taken into micro kjeldahl flask to which 1.1 gm catalyst mixture (K_2SP_4: $CuSO_4$. $5H_2O$: Se in the ratio of 100:10:1), and 6 ml H_2SO_4 were added. The flasks were swirled and heated 200^0C and added 3 ml H_2O_2 and then heating at 360^oC was continued until the digest was clear and colorless. After cooling, the content was taken into 100 ml volumetric flask and the volume was made up to the mark with distilled water. A reagent blank was prepared in a similar manner. These digests were used for nitrogen determination (Page *et al.*, 1982).

Then 20 ml digest solution was transferred into the distillation flask, Then 10 ml of H_3BO_3 indicator solution was taken into a 250 ml conical flask which is marked to indicated a volume of 50 ml and placed the flask under the condenser outlet of the distillation apparatus so that the delivery end dipped in the acid. Sufficient amount of 10N-NaOH solutions were added in the container connecting with distillation apparatus. Water runs through the condenser of distillation apparatus was checked. Operating switch of the distillation apparatus collected the distillate.

The conical flask was removed by washing the delivery outlet of the distillation apparatus with distilled water. Finally the distillates were titrated with standard 0.01 N H_2SO_4 until the color changes from green to pink (Bremner and Mulvaney, 1982). The amount of N was calculated using the following formula.

$$\% N = \frac{\langle T - B\rangle \times N \times 0.014 \times 100}{s}$$

Where,

T= Sample titration (ml) value of standard H_2SO_4

B = Blank titration (ml) value of standard H_2SO_4

N= Strength of H_2SO_4

S = Sample weight in gram

Available phosphorus (P)

Available phosphorus was extracted from soil with pH < 7 by shaking with 0.03 M NH_4F-0.025 M HCl (Bray and Kurtz, 1945) method. Phosphorus in soils with pH > 6 extraction with 0.5 M $NaHCO_3$ (Olsen *et al.,* 1954). The phosphorus in the extract was then determined by developing blue color using ascorbic acid of ammonium molybdate solution. The absorbance of the ammonium molybdate blue color was measured at 890 nm wave length by SHIMADZU UV-1900, UV-VIS Spectrophotometer and available P was calculated with the help of standard curve.

Exchangeable potassium (K)

Exchangeable K was determined by 1M NH_4OAc extraction methods and by using JENWAY PFP7 flame photometer and calibrated with a standard curve (Black *et al.,* 1965).

Available Sulphur (S)

Sulphur content was determined from the digest of the samples primary calcium phosphate ($Ca(H_2PO_4)_2H_2O$ solution, 37 % hydrochloric acid (HCl) and 6 ml phenol as described by (Fox *et al.,* 1964). The digested S was determined by developing turbidimetric reagent (polyvinylpyrrolidon and $BaCl_2$) by adding acid seed solution (69 % nitric acid, glacial acetic acid and sulphur stock solution).

3.6 Statistical analysis

Data recorded for yield and yield contributing characters including the nutrient content and uptake were compiled and tabulated in proper form for statistical analyses. Analysis of variance was done with the help of Statistix-10 computer package program developed by Russel (1986). The mean differences among the treatments were evaluated with DMRT test (Gomez and Gomez, 1984).

CHAPTER IV
Results and Discussion

Three separate experiments were conducted to achieve the objectives of the study. Experimental results of the research works are presented experiment wise with relevant head and sub heads as following:

4.1 Experiment 1: Effect of potassium on the growth and yield of wheat under water stress condition

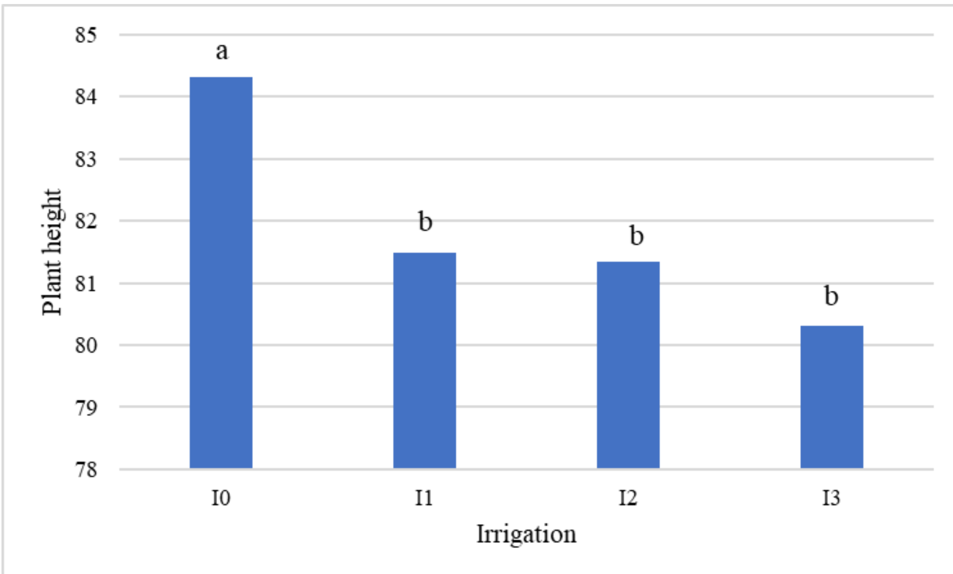
Results obtained from the present study regarding the influence of potassium on the growth and yield of wheat under water stress have been presented and discussed in this chapter. The results have been presented in Tables and Figures.

4.1.1 Yield and yield attributes of wheat

4.1.1.1 Plant height of wheat

4.1.1.1.1 Effect of water stress on plant height

Plant height of wheat at harvest varied significantly due to the effect of water stress while plant height ranged from 80.30 to 84.30 cm (Figure 4.1). All the treatments were significantly different from the control (normal) condition (I_0). The tallest plant with 84.30 cm height was found in control (normal) condition (I_0) where proper irrigation was applied in different growth stage (Table 4.1). The shortest plant height 80.30 cm was found in treatment (I_3), in which water stress was applied in the milking stage and another two treatments had no significant difference with treatment I_3. These results revealed that water stress in vegetative stage; flower initiation stage and milking stage have almost same effect on plant height reduction compared to control (normal) condition. Islam (1997) reported that plant height increased with increasing number of irrigations which also supports the findings of this experiment.



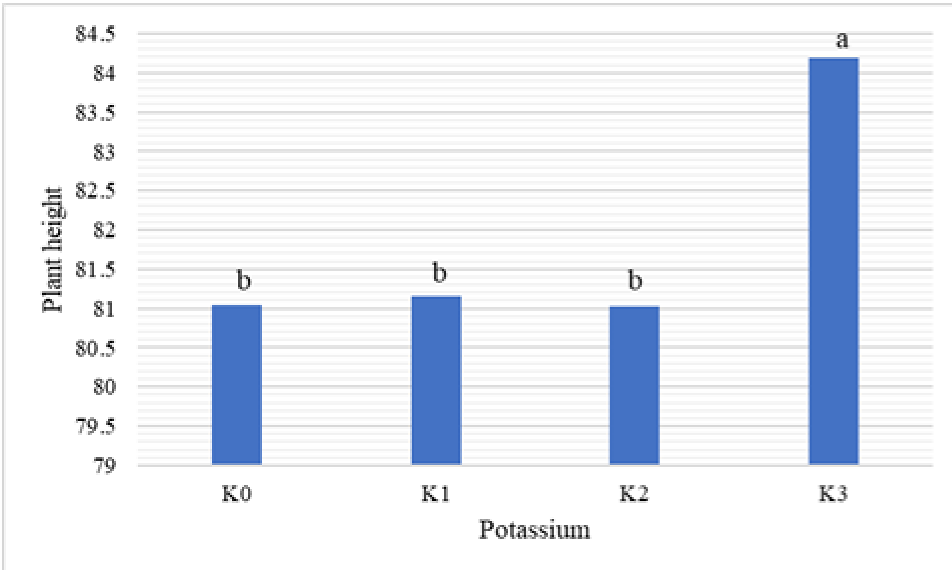
I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Figure 4.1: Effect of water stress condition on plant height of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.1.2 Effect of different doses of potassium on plant height

Height is an important trait for better yield of plant. Difference in plant height was observed due to the variation of potassium doses in wheat plants. Plant height was highest (84.2 cm), in treatment K_3 where the dose of potassium was also highest and it is significantly different from all other treatments (Figure 4.2). Lowest plant height (81.0 cm) was recorded in control condition where no potassium was applied (Table 4.2). Other two treatments K_1 and K_2 having the dose of potassium 60 kg K/ha and 90 kg K/ha had no significant difference with the control condition. These results indicate that only the highest dose of potassium (K_3) of

120 kg K/ha had significant effect on plant height. Saren and Jana (2008) found that application of 50 kg K/ha as top dressing after irrigation gave the longest plant.



K_0 = 0 kg K /ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Figure 4.2: Effect of different doses of potassium fertilizer on plant height of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.2 Total number of tillers per plant

4.1.1.2.1 Effect of water stress condition on total number of tillers per plant

Tiller number is an important parameter that influence crop yield. Supply of nutrient plays a major role on total tiller number per plant, while proper irrigation ensures the availability of the nutrients for plant. Here in different water stress condition, varied numbers of tillers were observed (Figure 4.3). Highest number of tillers (4.61) in control condition had no significant difference with treatment I_1 where water stress was applied during their vegetative stage (Table 4.1). But they were significantly different from other two treatments I_2 and I_3 where water stress was applied to the plants in their flowering and milking stage.

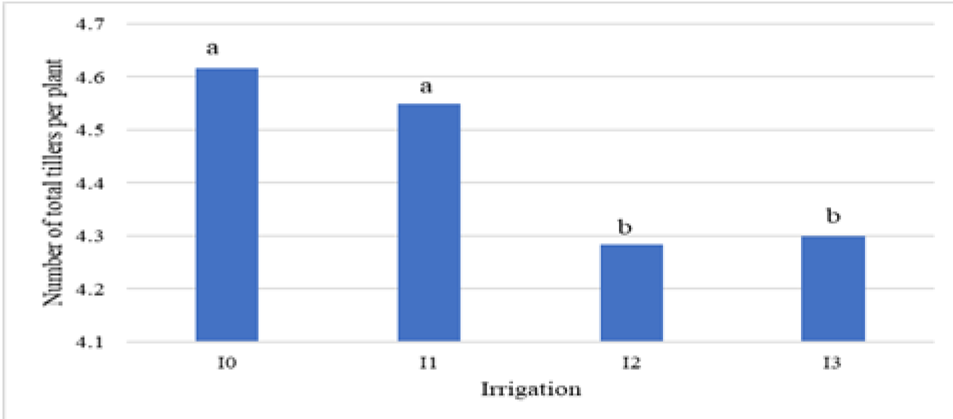
Table 4.1 Effect of irrigation on plant height and yield contributing characters of Wheat

Irrigation	Plant height (cm)	Number of tillers per plant	Number of effective tillers per plant	Number of non-effective tillers per	Length of Flag leaf (cm)	Ear length (cm)
I_0	84.30a	4.61a	4.70a	0.61b	17.55a	15.47a
I_1	81.50b	4.55a	4.40ab	0.67b	16.91a	15.32a
I_2	81.33b	4.28b	4.20b	0.94a	16.70ab	15.52a
I_3	80.30b	4.30b	4.30ab	0.91a	15.51a	15.52a
$LSD_{(0.05)}$	**2.39**	**0.50**	**0.10**	**0.20**	**1.14**	**0.65**
CV%	**1.1719**	**0.2455**	**8.24**	**4.17**	**5.58**	**3.19**

I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Different letters indicates treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Results revealed that water stress during the flowering stage caused lowest number of tillers, which were 4.28. Application of two irrigations at crown root initiation stage and pre flowering stage ensured the optimum vegetative growth of the wheat as referred by Meena *et al.* (1998).

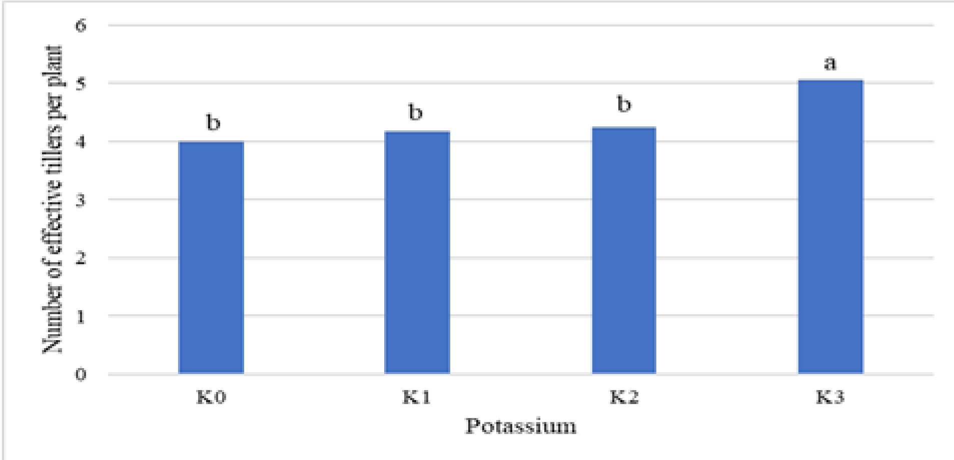


I_0 = Control (normal irrigation)
I_1 = Water stress at vegetative stage
I_2 = Water stress at flower initiation stage
I_3 = Water stress at milking stages

Figure 4.3: Effect of water stress condition on total number of tillers per plant of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.2.2 Effect of different doses of potassium fertilizer on number of effective tillers per plant

From this study, significant effects were not found in different doses of potassium were applied to observe the variation in effective tiller numbers in wheat. Highest number of effective tillers (5.20) was found in treatment K_3 due to the application of highest amount (120 kg K/ha) of potassium. Treatment K_3 was significantly different from other treatments (Table 4.2). Lowest number of effective tillers (4.15) was found in control condition, which was statistically similar to the treatment K_1 (4.20) treatment and K_2 (4.15). No significant difference was found in number of tillers due to 60 kg K/ha and 90kg K/ha of potassium application (Figure 4.4).



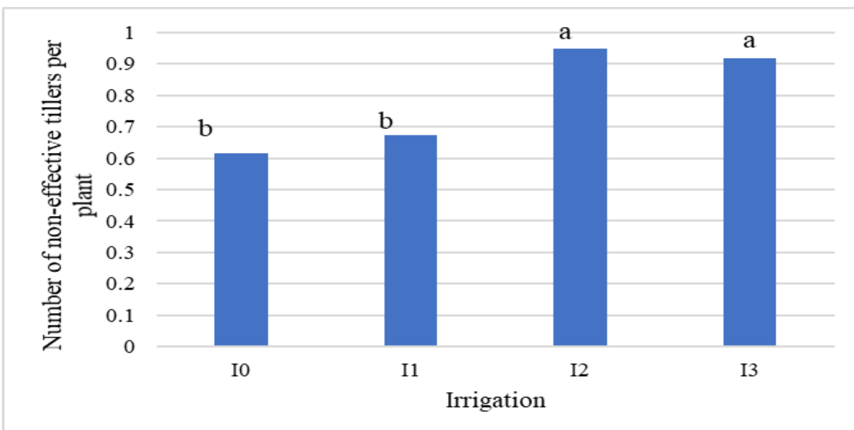
K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Figure 4.4: Effect of different doses of potassium fertilizer on number of effective tillers per plant of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.3 Number of non-effective tillers per plant

4.1.1.3.1 Effect of different doses of water stress on number of non-effective tillers per plant

Different treatments of water stress in different growth stage of wheat showed variation in number of non-effective tillers. Highest number of non-effective tillers was 0.94 found in treatment I_2 having water stress in flowering initiation stage and it had no significant difference with the treatment I_3 where water stress was provided in milking stage. Lowest number of non-effective tillers were (0.61) found in treatment I_0 where water stress was applied and this had no significant difference with the treatment I_1 (Table 4.1). Results indicated that flowering initiation stage was most critical growth stage for wheat, as water stress in this stage caused highest non-effective tillers (Figure 4.5). As well as water stress in vegetative stage had no significant effect on producing non effective tillers. Zhai *et al.* (2003) reported that water stress significantly inhibited the number of tillers of winter wheat.

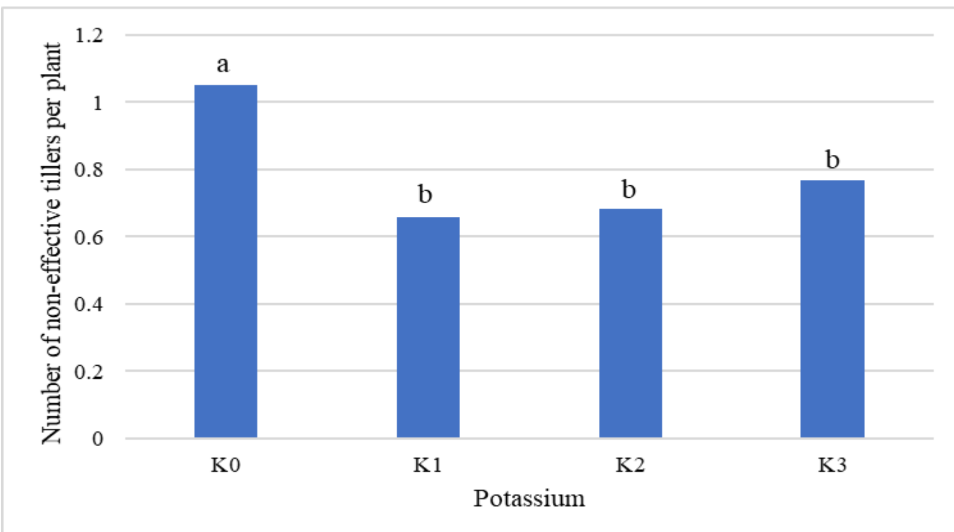


I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Figure 4.5: Effect of water stress condition on number of non-effective tillers per plant of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.3.2 Effect of different doses of potassium fertilizer on number of non-effective tillers per plant

Various treatments of potassium fertilizer caused variation in non-effective tillers per plant of wheat. Highest number of non-effective tillers plant^{-1} was (1.08) observed in treatment K_0, which was significantly superiors to all other treatments (Figure 4.6). Lowest number of non-effective tillers 0.62 was in treatment K_1, where 60 kg K/ha potassium was applied to the plants (Table 4.2). Treatment K_1 had no significant difference with the other treatments K_2 and K_3 where 90 kg K/ha and 120 kg K/ha potassium was applied to the plants. Results revealed that control condition had significant difference in producing non-effective tillers with the other treatments.



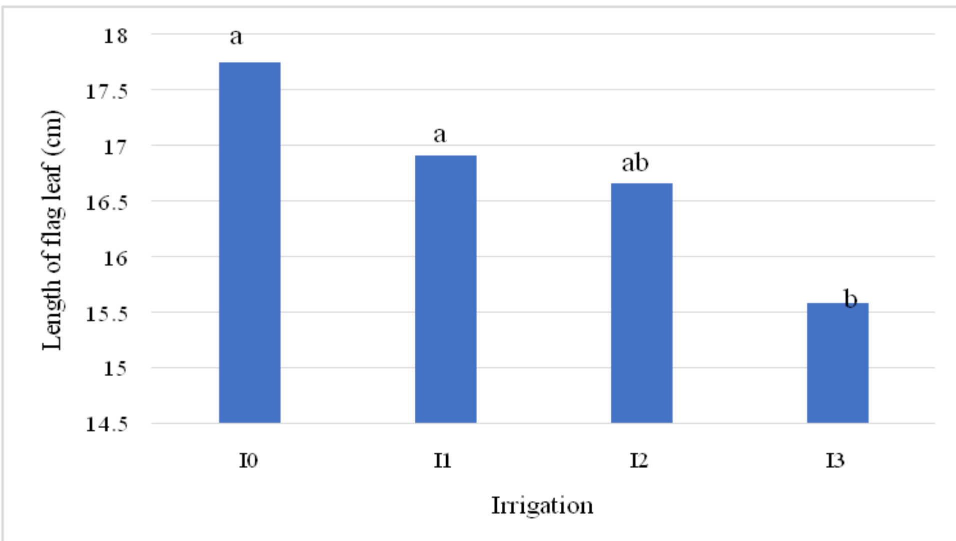
K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Figure 4.6: Effect of different doses of potassium fertilizer on number of non-effective tillers per plant of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.4 Length of flag leaf

4.1.1.4.1 Effect of water stress condition on the length of flag leaf

Length of flag leaf is an important trait contributing yield of wheat. Here different treatments of irrigation in different growth stage of wheat had variation in the length of flag leaf. Highest length of the flag leaf (17.55 cm) was observed in treatment I_0, where proper irrigation was applied to the plants. Lowest length of flag leaf was (15.51cm) in treatment I_3 having water stress in milking stage (Figure 4.7). Other treatments I_1 and I_2 had no significant difference with I_0 in their flag leaf length. But I_3 was significantly different from all other treatments except I_2 (Table 4.1). Results indicate that milking stage is the most critical stage for flag leaf length as providing at this stage caused shortest length of flag leaf.

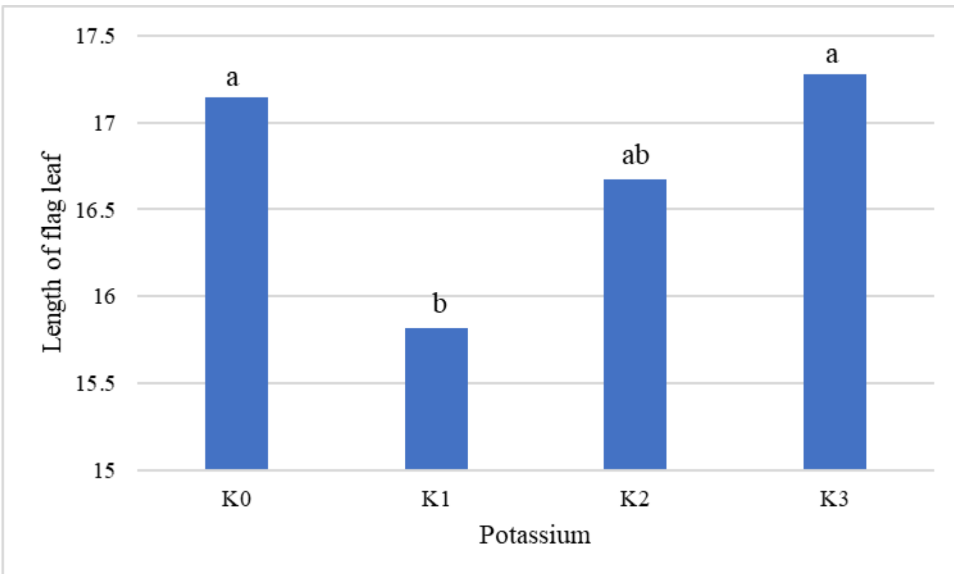


I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Figure 4.7: Effect of water stress condition on the length of flag leaf of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.4.2 Effect of potassium fertilizer on the length of flag leaf

Variation in different nutrient content can produce varied length of flag leaf. In this study, different doses of potassium were applied for which difference in the length of flag leaf was observed. Highest flag leaf length (17.25 cm) was found in treatment K_3 where 120 kg K/ha of potassium was applied (Figure 4.8). Treatment K_3 had no significant difference with treatment K_0 (17.20 cm) (Table 4.2). Shortest flag leaf length was (15.55 cm) in treatment K_1 having the dose of 60 kg K/ha potassium. Treatment K_1 was significantly different from all the other treatments except K_2.



K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Figure 4.8: Effect of different doses of potassium fertilizer on the length of flag leaf of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Table 4.2 Effect of Potassium on plant height and yield contributing characters of wheat

Potassium	Plant height (cm)	Number of tillers per plant	Number of effective tillers per plant	Number of Non-effective tillers per plant	Length of Flag leaf (cm)	Ear length (cm)
K_0	81.0b	4.23b	4.15b	1.08a	17.20a	15.18a
K_1	81.20b	4.20b	4.15b	0.62b	15.55b	15.55a
K_2	81.0b	4.15b	4.20b	0.68b	16.67ab	15.57a
K_3	84.2a	5.20b	5.20a	0.76b	17.25a	15.60a
$LSD_{(0.05)}$	**2.39**	**0.50**	**0.44**	**0.41**	**1.14**	**0.65**
CV%	**1.17**	**0.24**	**2.21**	**2.04**	**5.58**	**3.19**

K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Different letters indicates treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.2 Interaction effect of water stress condition and potassium fertilizer on different plant growth parameters of wheat

Interaction effect of water stress and potassium fertilizer on different plant growth parameters has been shown in (Table 4.3). From this table results demonstrates that plant height ranged from lowest (78.73 cm) in the treatment combination I_3K_0 to the highest (84.69 cm) in the treatment combination of I_0K_3. The growth height was statistically significant with all other treatment except I_0K_0 treatment. Total numbers of tillers were lowest (3.87) in the treatment of I_3K_1 which was statistically similar to the I_2K_0. The highest numbers of tillers were (5.53) observed in the treatment I_0K_3. Numbers of effective tillers ranged from 3.73 to 5.4, number of non-effective tillers was ranged from 0.33 to 1.33 found in treatment I_2K_3 which is statistically similar to I_2K_1 and I_1K_2, on the other hand highest non-effective tiller number was found in I_3K_0 1.33. The length of flag leaf ranged from lowest 15 cm in I_3K_2 to the highest (19.29 cm) in I_0K_3 treatment combination.

Table 4.3: Interaction effect of water stress condition and potassium fertilizer on different growth parameters and yield contributing characters of wheat

Interaction	Plant height (cm)	Number of total tillers per plant	Number of effective tillers per plant	Number of non-effective tillers per plant	Length of flag leaf (cm)	Ear length (cm)
$I_0 \times K_0$	78.73b	4.13b-d	3.73d	1.33a	16.1b-e	15.48ab
$I_0 \times K_1$	80.07ab	4.20b-d	4.27cd	1.07ab	15.26de	14.97b
$I_0 \times K_2$	81.13ab	4.27b-d	4.33cd	0.87ab	18.11a-c	15.22b
$I_0 \times K_3$	84.69a	5.53a	5.33ab	0.80ab	19.29a	16.55a
$I_1 \times K_0$	82.73ab	4.47b-d	4.6-a-d	0.87ab	17.53a-d	14.81b
$I_1 \times K_1$	81.87ab	4.46b-d	4.40cd	0.50ab	16.75b-e	15.65ab
$I_1 \times K_2$	79.79b	4.21b-d	4.53a-d	0.40b	17.10a-e	15.51ab
$I_1 \times K_3$	82.89ab	5.07a-c	5.07a-c	0.93ab	16.25b-e	15.35ab
$I_2 \times K_0$	78.75b	3.87d	3.93d	0.93ab	16.58b-e	15.35ab
$I_2 \times K_1$	82.66ab	4.21b-d	4.20cd	0.33b	15.89c-e	15.71ab
$I_2 \times K_2$	81.82ab	4.07cd	4.07d	0.87ab	16.47b-e	16.03ab
$I_2 \times K_3$	82.1ab	5.00a-c	4.47b-d	0.33b	17.69a-c	15.06b
$I_3 \times K_0$	81.05ab	5.13ab	5.40a	1.00ab	15.88c-e	15.22b
$I_3 \times K_1$	80.05ab	3.87d	3.8d	0.73ab	15.38de	15.90ab
$I_3 \times K_2$	81.37ab	4.07cd	4.07d	0.60ab	15.0e	15.53ab
$I_3 \times K_3$	82.03ab	4.47b-d	3.73d	1.07ab	18.37ab	15.15b
LSD $_{(0.05)}$	**4.78**	**1.00**	**0.88**	**0.83**	**2.28**	**1.30**
CV%	**2.34**	**4.9**	**4.3**	**4.01**	**1.17**	**6.39**

Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

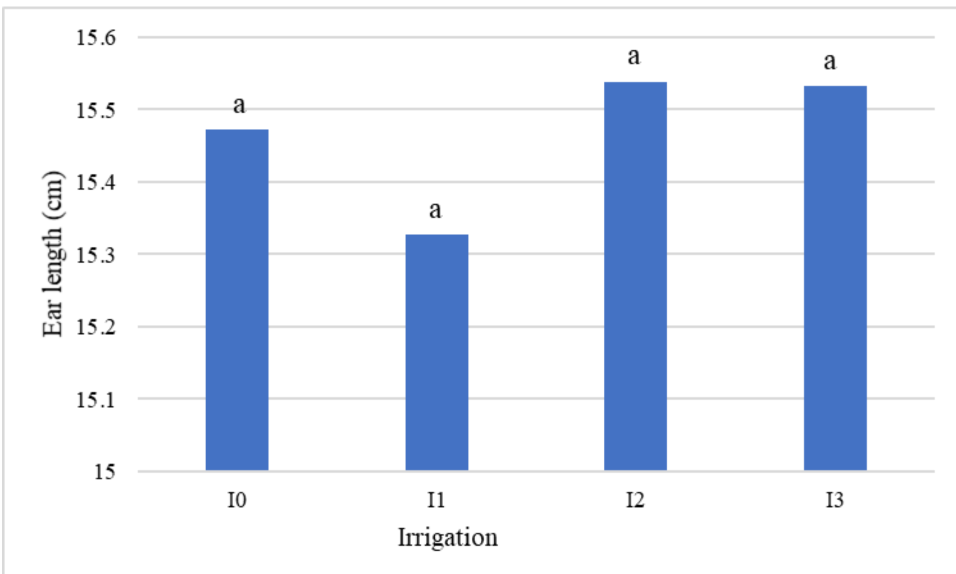
I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

K_0= 0 kg K/ha, K_1= 60 kg K/ha, K_2= 90 kg K/ha, K_3= 120 kg K/ha

4.1.1.5 Ear length

4.1.1.5.1 Effect of water stress condition on ear length

Ear length has significant impact on the yield quality of wheat. Water stress in different growth stage causes variation in the ear length. In this study, the effect of water condition in different growth stage was observed (Table 4.1). The lowest ear length (15.32 cm) was found in treatment I_1 where water was applied in vegetative stage (Figure 4.9). Highest ear length (15.52) cm was found in treatment I_2 and I_3 where water was applied in flowering initiation and milking stage respectively. But all the values were statistically similar as they had no significant difference among each other.

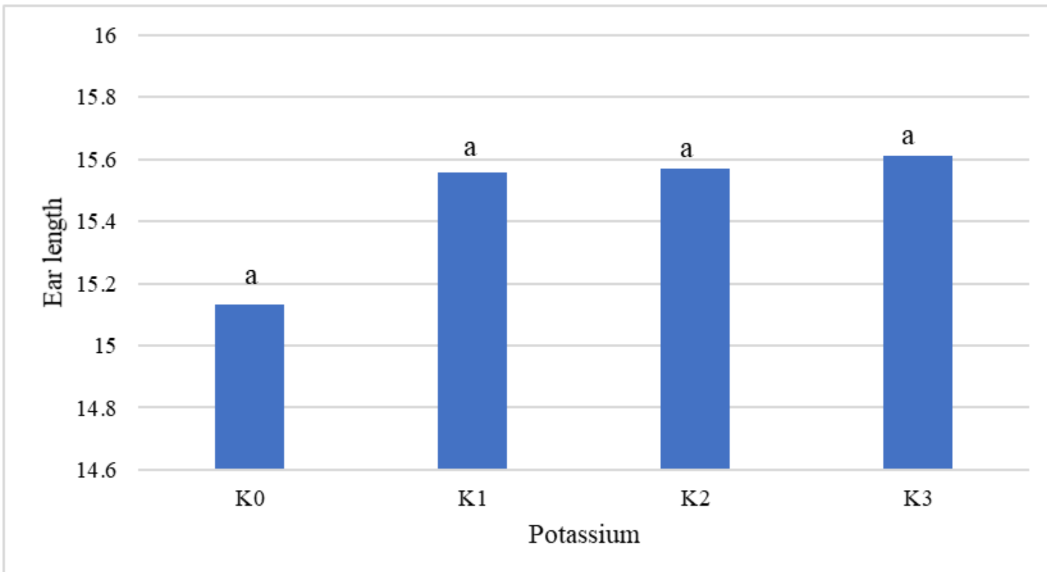


I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages

Figure 4.9: Effect of water stress condition on ear length of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.5.2 Effect of potassium fertilizer on ear length

Potassium fertilizer doses also have effect on wheat ear length. From this study lowest ear length 15.18 cm was found in treatment K_0. The highest ear length (15.60 cm) was found in treatment K_3 and K_2 (Table 4.2). Results revealed that, different potassium doses had no significant effect on ear length as all of them were statistically similar to each other (Figure 4.10).



K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

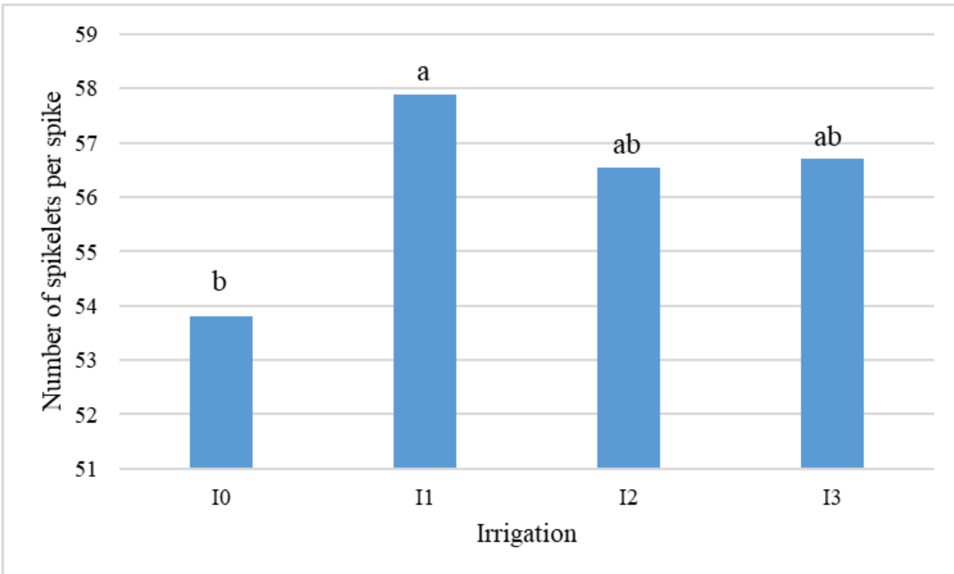
Figure 4.10: Effect of different doses of potassium fertilizer on ear length of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.6 Number of spikelet per spike

4.1.1.6.1 Effect of water stress condition on number of spikelet per spike

Number of spikelet per spike of wheat showed statistically significant variation due to different levels of irrigation (Figure 4.11). The maximum number of spikelet per spike

(57.9) was observed from treatment I_1, where water was applied in vegetative stage and it had no significant difference with treatment I_2 and I_3 except I_0 (Table 4.4). Whereas the minimum numbers of spikelet per spike (53.8) was observed from I_0 which was significantly different from the treatment I_1 producing maximum spikelet per spike. Naser (1996) reported that the highest number of grains per spike were recorded when two irrigations were applied.

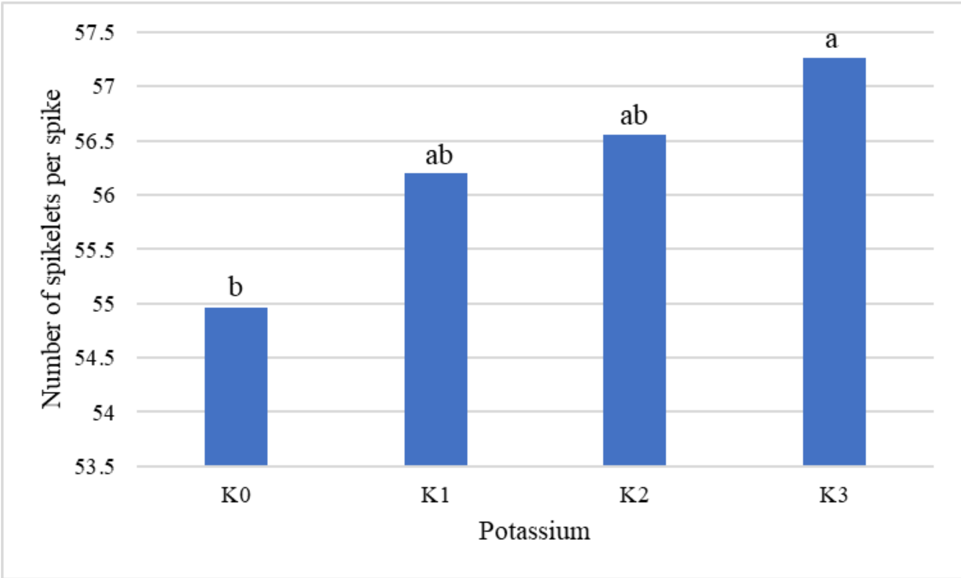


I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Figure 4.11: Effect of water stress condition on number of spikelet per spike of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.6.2 Effect of different doses of potassium fertilizer on number of spikelet per spike

There was a statistically significant variation was observed in terms of number of spikelet per spike of wheat due to different levels of potassium fertilizer (Figure 4.12). The maximum number of spikelet per spike (57.25) was observed from K_3 treatment, which was statistically similar to K_1 and K_2 but significantly different with K_0 (Table 4.5). The minimum number of spikelet per spike (54.90) was observed in K_0 which was significantly different from the treatment K_3.



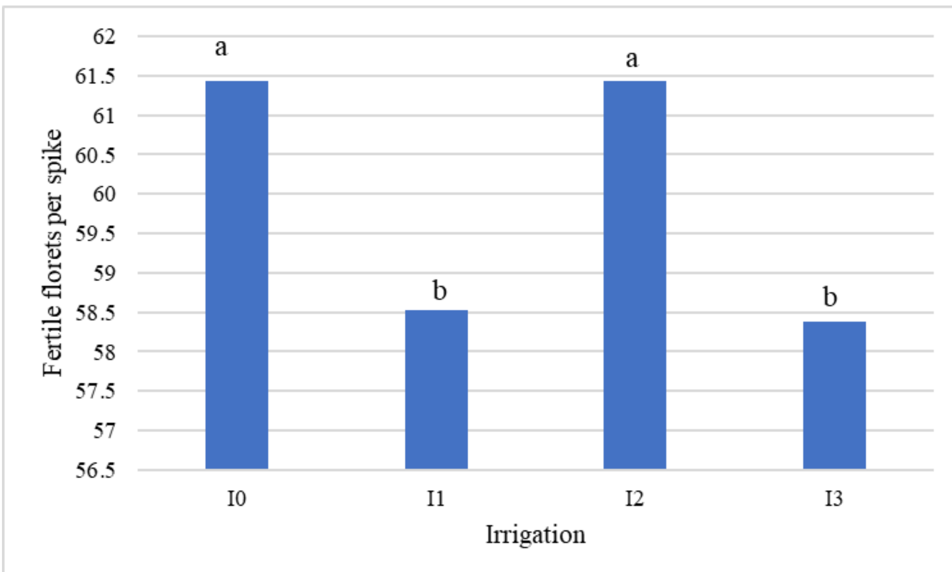
K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Figure 4.12: Effect of different doses of potassium fertilizer on number of spikelet per spike of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.7 Number of fertile florets per spike

4.1.1.7.1 Effect of water stress condition on number of fertile florets per spike

Number of fertile florets varied due to application irrigation in different growth stage of wheat. Maximum number of fertile florets (61.40) were found from the treatments I_0 and I_2 (Figure 4.13), both of them were statistically similar to each other (Table 4.4). Minimum number of fertile florets (58.40) were found in the treatment I_3 where water stress was provided in the milking stage, it was statistically similar to treatment I_2 (58.50) but significantly different with other treatments.

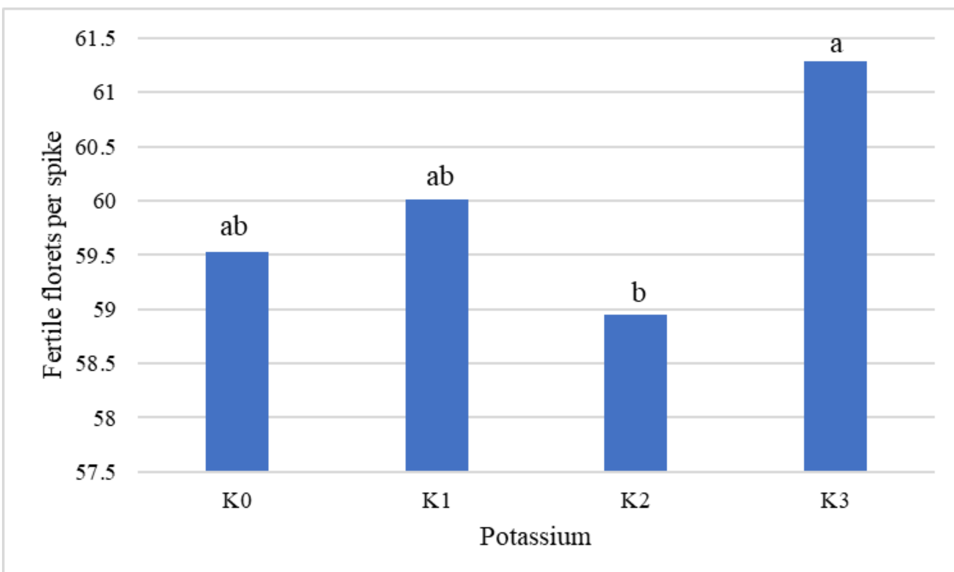


I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Figure 4.13: Effect of water stress condition on number of fertile florets per spike of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.7.2 Effect of different doses of potassium fertilizer on number of fertile florets per spike

Number of fertile florets varied due to different doses of potassium fertilizer in wheat. Maximum number of fertile florets (61.25) were found from the treatments K_3 and it was statistically similar with treatment K_1 and K_0 (Figure 4.14). Minimum number of fertile florets (58.90) were found in the treatment K_2 where 90 kg K/ha potassium was provided; it was significantly different with other treatments but statistically similar with treatment K_1 (Table 4.5). Results indicated that highest amount of potassium application induced in the production of higher number fertile floret.



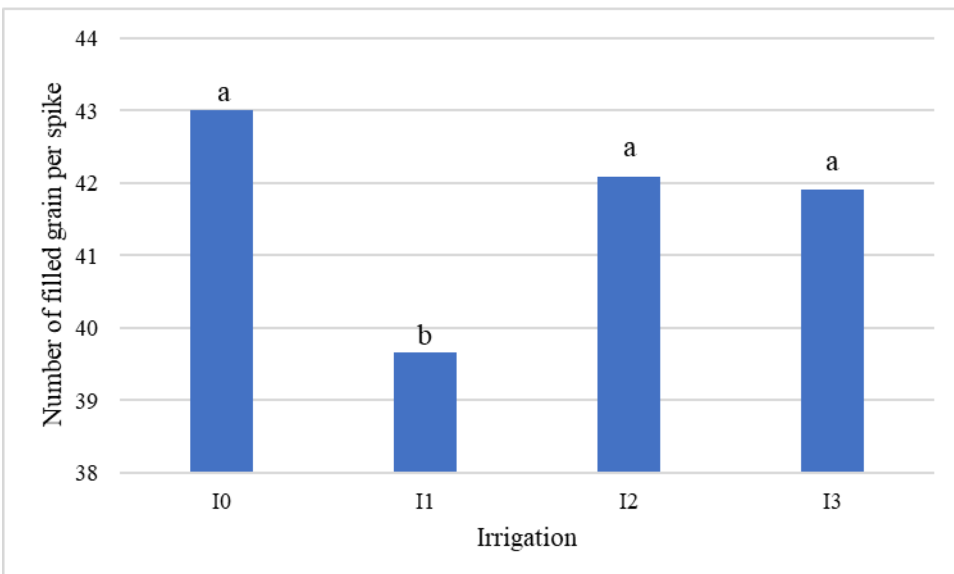
K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha.

Figure 4.14: Effect of different doses of potassium fertilizer on number of fertile florets per spike of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.8 Filled grain per spike

4.1.1.8.1 Effect of water stress condition on number of filled grains per spike

Number of filled grains per spike of wheat showed statistically significant variation due to different levels of irrigation (Figure 4.15). The maximum number of filled grains per spike (43.0) was observed from I_0 which was statistically similar with I_2 (42.10) and I_3 (41.90), whereas the minimum number (39.80) was observed from I_1 and it was significantly different from all other treatments (Table 4.4). Gupta *et al.* (2001) reported that number of grains decreased to a greater extent when water stress was imposed at the anthesis stage.

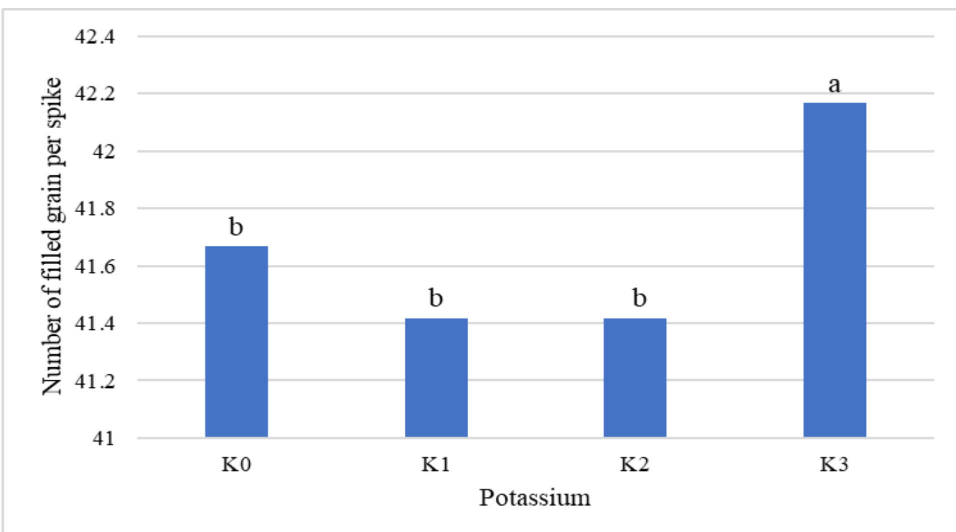


I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Figure 4.15: Effect of water stress condition on number of filled grains per spike of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.8.2 Effect of different doses of potassium fertilizer on number of filled grains per spike

Statistically significant variation was observed in terms of number of filled grains per spike of wheat due to different levels of potassium fertilizer (Figure 4.16). The maximum number of filled grains per spike (42.18) was observed from K_3 treatment, having significant difference with other treatments (Table 4.5). While the minimum number of filled grains per spike (41.40) was found in K_1 followed by K_2 (41.41), both of them were statistically similar to treatment K_0. Results indicated that, 60 kg K/ha and 90kg K/ha potassium application had no significant difference with K_0 that is 0 kg K/ha potassium application in case of producing filled grains per spike. Only 120 kg K/ha potassium application resulted into higher filled grain production.



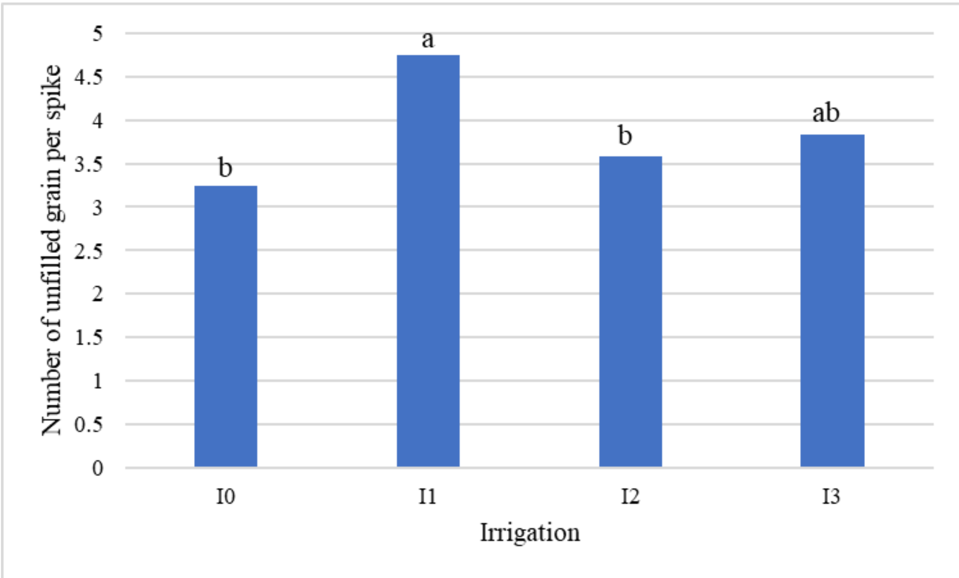
K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Figure 4.16: Effect of different doses of potassium fertilizer on number of filled grains per spike of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.9 Number of unfilled grains per spike

4.1.1.9.1 Effect of water stress condition on number of unfilled grains per spike

Number of unfilled grains per spike of wheat showed statistically significant variation due to different levels of irrigation (Figure 4.17). The maximum number of unfilled grains per spike (4.70) was observed from I_1. The minimum number of unfilled grains per spike (3.25) was observed from I_0 which was closely followed (3.60) by in treatment I_2 (Table 4.4). Both of them are statistically similar to each other but significantly different with I_0.

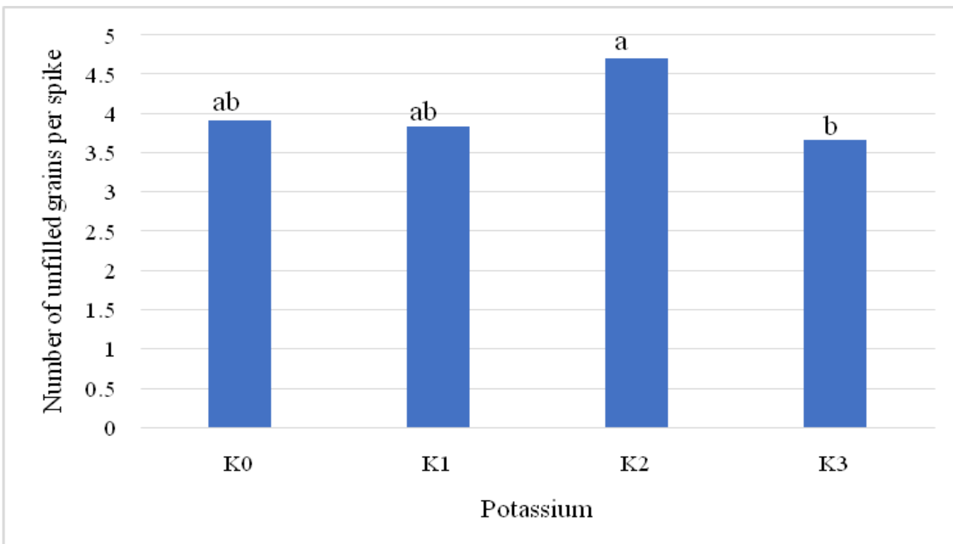


I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Figure 4.17: Effect of water stress condition on number of unfilled grains per spike of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.9.2 Effect of different doses of potassium fertilizer on number of unfilled grains per spike

Statistically significant variation was observed in terms of number of unfilled grains per spike of wheat due to different levels of potassium fertilizer (Figure 4.18). The maximum number of unfilled grains per spike (4.70) was observed from K_2 treatment, while the minimum number of unfilled grains per spike (3.60) was found in K_3 (Table 4.5).



K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Figure 4.18: Effect of different doses of potassium fertilizer on number of unfilled grains per spike of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Table 4.4 Effect of water stress on yield contributing characters of wheat

Irrigation	Number of spikelet per spike	Number of fertile florets per spike	Number of filled grain per spike	Number of un-field grain per spike	Total grains per spike	1000 grains weight (g)
I_0	53.81b	61.40a	43.0a	3.25b	46.25a	52.40a
I_1	57.90a	58.53b	39.80b	4.70a	44.40b	52.0a
I_2	56.55ab	58.50a	42.10a	3.60b	45.60ab	52.30a
I_3	56.71ab	58.40b	41.90a	3.83ab	45.70ab	50.90b
LSD $_{(0.05)}$	**1.29**	**5.53**	**1.74**	**0.97**	**1.43**	**1.62**
CV%	**6.5**	**2.70**	**8.5**	**4.7**	**7.00**	**7.96**

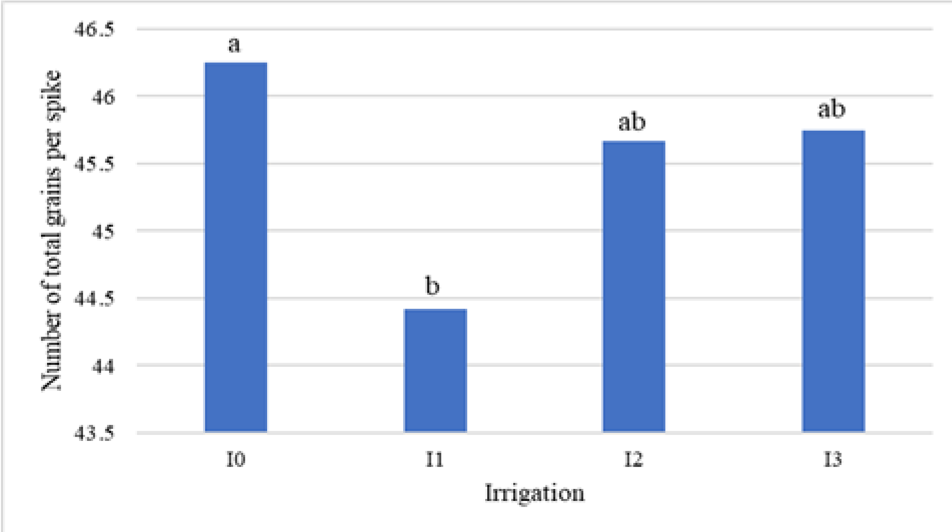
I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Different letters indicates treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.10 Total grains per spike

4.1.1.10.1 Effect of water stress condition on number of total grains per spike

Number of total grains per spike of wheat showed statistically significant variation due to different levels of irrigation (Figure 4.19). The maximum number of total grains per spike (46.25) was observed from I_0 which was statistically similar (45.60) and (45.70) with I_2, I_3 and significantly different from I_1 (Table 4.4). While the minimum numbers of total grains per spike (44.40) was observed from I_1. Islam and Islam, (1991) observed that irrigation had significant influence of grains per spike.

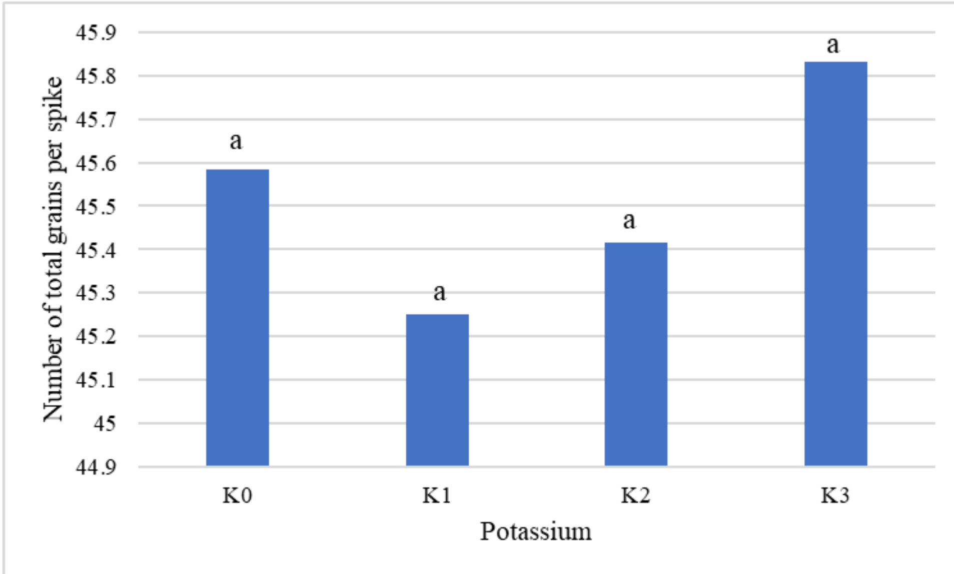


I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Figure 4.19: Effect of water stress condition on number of total grains per spike of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.10.2 Effect of different doses of potassium fertilizer on number of total grains per spike

Statistically significant variation was observed in terms of number of total grains per spike of wheat due to different levels of potassium fertilizer (Figure 4.20). The maximum number of total grains per spike (45.82) was observed from K_3 treatment, which was statistically similar (45.59) to K_0 followed by K_2 (45.42) (Table 4.5). While the minimum number of total grains per spike (45.25) was found in K_1. But there was no significant difference among the treatments in case of total grain.



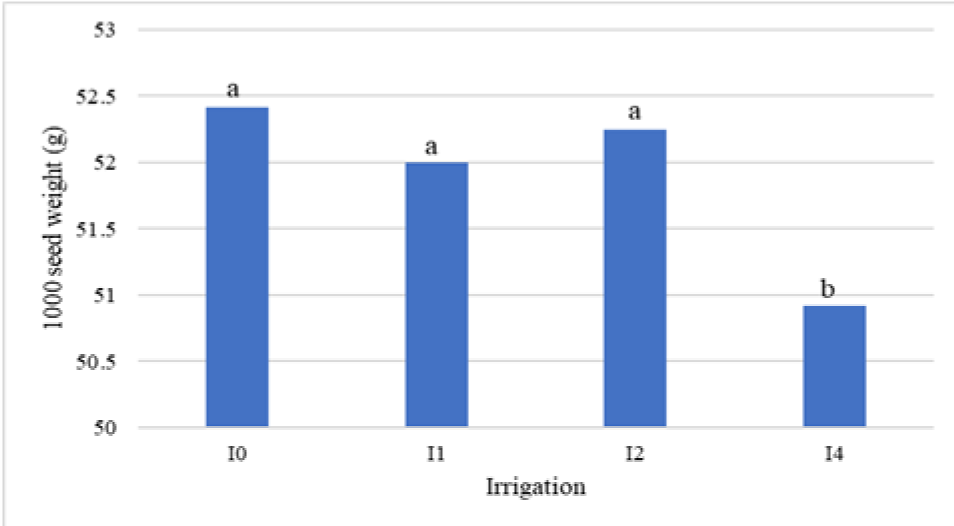
K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Figure 4.20 Effect of different doses of potassium fertilizer on number of total grains per spike of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.11 1000 grains weight

4.1.1.11.1 Effect of water stress condition on 1000 grains weight

Weight of 1000 grains of wheat showed statistically significant variation due to different levels of irrigation (Figure 4.21). The highest weight of 1000 grains (52.40) g was observed from I_0 which was statistically similar with I_2 (52.30 g) and I_1 (52.0 g) (Table 4.4). While the lowest weight of 1000 grains (50.90 g) was observed from I_3 which is significantly different from all other treatments. Islam and Islam, (1991) observed that irrigation had no influence of 1000 grain weight. Zarea and Ghodsi (2004) in Iran and found that number of spike/m^2 and 1000-grains weight decreased with increasing irrigation intervals.

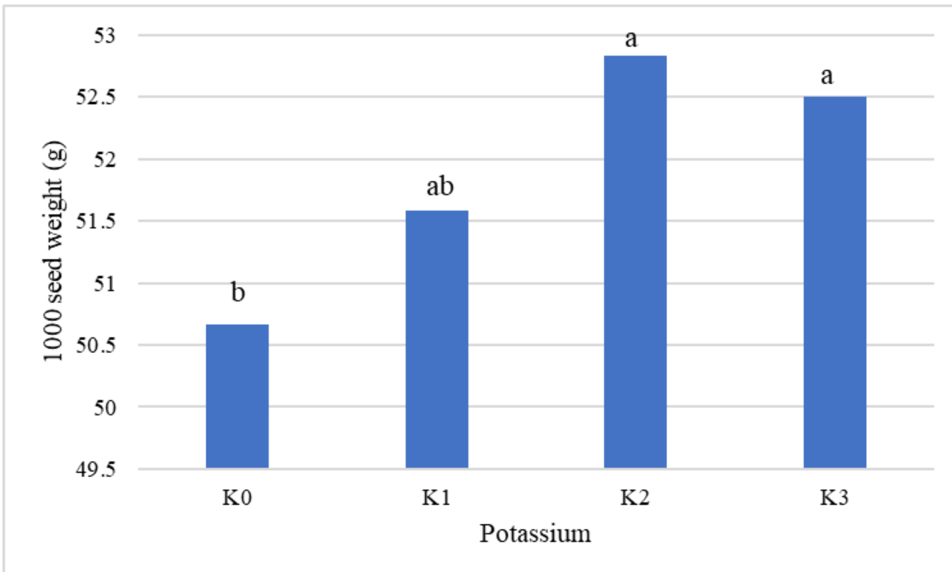


I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Figure 4.21 Effect of water stress condition on 1000 grains weight of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.11.2 Effect of different doses of potassium fertilizer on 1000 grains weight

Statistically significant variation was observed in terms of weight of 1000 grains of wheat due to different levels of potassium fertilizer (Figure 4.22). The highest weight of 1000 grains (52.75 g) was observed from K_2 treatment, which was statistically similar with K_3 (52.50 g) and K_1 (51.60 g) (Table 4.5). The lowest weight of 1000 grains (50.70 g) was found in K_0 and it was significantly different from all the other treatments except K_1.



K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Figure 4.22 Effect of different doses of potassium fertilizer on 1000 grains weight of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Table 4.5 Effect of different doses of potassium yield contributing characters of wheat

Potassium	Number of spikelet per spike	Number of fertile florets per spike	Number of filled grain per spike	Number of un-field grain per spike	Total grains per spike	1000 grains weight (g)
K_0	54.96b	59.53ab	41.66a	3.91ab	45.59a	50.70b
K_1	56.20ab	60.01ab	41.40a	3.83ab	45.25a	51.60ab
K_2	56.55ab	58.90b	41.41a	4.70a	45.42a	52.75a
K_3	57.26a	61.25a	42.18a	3.60b	45.82a	52.50a
LSD $_{(0.05)}$	**1.73**	**5.53**	**1.74**	**0.97**	**1.43**	**1.62**
CV%	**2.45**	**2.70**	**8.6**	**4.75**	**7.00**	**0.80**

K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Different letters indicates treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.3 Interaction effect of water stress condition and potassium fertilizer on different plant growth parameters of wheat

Effect of interaction of water stress and potassium fertilizer on different plant growth parameters has been shown in (Table 4.6). From this table results demonstrate that ear length ranged from lowest (14.81 cm) in the treatment combination I_1K_0 to the highest (16.55 cm) in the treatment combination of I_0K_3. Number of spikelets per spike were lowest (52.73) in the treatment interaction of I_2K_3 and highest number spikelet per spike (59.47) was observed in the treatment interaction I_3K_2. Number of fertile florets per spike ranged from (57) in I_3K_2 treatment combination to the highest number (64.87) in the interaction of I_0K_0. Numbers of filled grains per spike were found lowest (38.33) in treatment interaction I_0K_2 and highest filled grains number was found in I_1K_0 (44) which was statistically similar to I_1K_1. Number of unfilled grains per spike ranged from lowest (2.33) in I_1K_1 to the highest number (5) in I_0K_1 which was statistically similar to I_0K_2 interaction. The maximum number of total grains per spike (47.33) was observed from 1_3K_3, while the minimum number of total grains per spike (43.33) was recorded from I_0K_2. The highest weight of 1000 grains (54.67 g) was observed from I_1K_3, again the lowest weight of 1000 grains (49.67 g) was recorded from I_3K_0.

Table 4.6. Interaction of water stress condition and potassium fertilizer on different yield contributing characters of wheat

Interaction	Number of spikelets per spike	Number of fertile florets per spike	Number of filled grains per spike	Number of unfilled grains per spike	Number of total grains per spike	1000 grains weight (g)
$I_0 \times K_0$	54.80c-g	56.87e	41.33a-e	3.67a-c	45.67a-c	50.33cd
$I_0 \times K_1$	53.07fg	64.60ab	39.00de	5.00a	44.00bc	52.00a-d
$I_0 \times K_2$	53.53e-g	61.60bc	38.333e	5.00a	43.33c	51.67a-d
$I_0 \times K_3$	53.87d-g	61.47bc	40.00c-e	4.67ab	44.6a-c	54.00ab
$I_1 \times K_0$	58.73ab	61.20cd	44.00a	3.33a-c	47.33a	50.00cd
$I_1 \times K_1$	59.2ab	60.07c-e	44.00a	2.33c	46.33ab	51.00b-d
$I_1 \times K_2$	56.67a-e	59.93c-e	42.00a-d	4.00a-c	46.00a-c	52.33a-d
$I_1 \times K_3$	57.00a-d	59.87c-e	42.00a-d	3.33a-c	45.33a-c	54.67a
$I_2 \times K_0$	57.53a-c	59.67c-e	41.00a-e	4.00a-c	45.00a-c	51.00b-d
$I_2 \times K_1$	56.53a-e	59.27c-e	42.00a-d	3.67a-c	45.67a-c	52.67a-d
$I_2 \times K_2$	59.40ab	58.73c-e	42.33a-d	3.67a-c	46.00a-c	54.33a
$I_2 \times K_3$	52.73g	58.67c-e	43.00a-c	3.00bc	46.00a-c	51.00b-d
$I_3 \times K_0$	55.13c-g	57.8de	40.33b-e	4.00a-c	44.33bc	49.67d
$I_3 \times K_1$	56.00b-g	57.53e	40.67a-e	4.33ab	45.00a-c	50.67cd
$I_3 \times K_2$	59.47a	57.00e	43.00a-c	3.33a-c	46.33ab	53.00a-c
$I_3 \times K_3$	56.27a-f	64.87a	43.6ab	4.33ab	47.33a	52.00a-d
LSD (0.05)	**9.49**	**11.06**	**3.48**	**1.94**	**2.86**	**3.25**
CV%	**4.64**	**5.41**	**1.71**	**0.95**	**1.41**	**1.59**

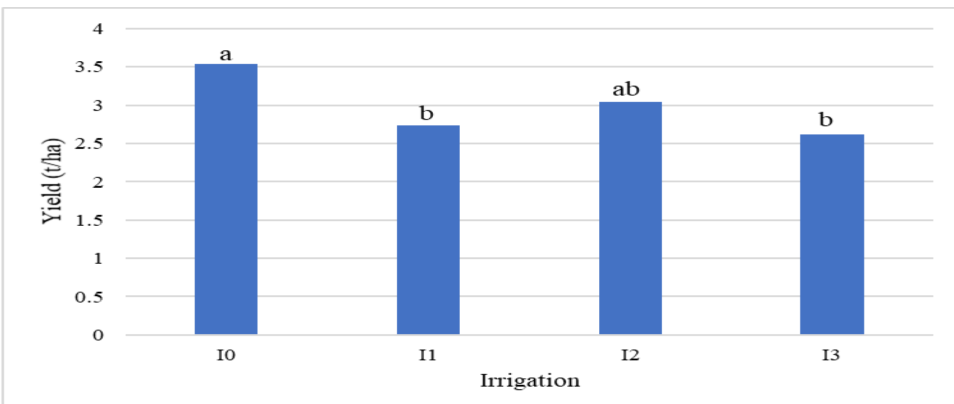
Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.
I_0 = Control (normal condition),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

K_0= 0 kg K/ha K_1= 60 kg K/ha K_2= 90 kg K/ha K_3= 120 kg K/ha

4.1.1.12 Yield of wheat

4.1.1.12.1 Effect of water stress condition on yield of wheat

There was statistically significant variation in terms of grain yield of wheat showed due to different levels of irrigation (Figure 4.23). The highest grain yield (3.60 t/ha) was observed from I_0 which was statistically similar (3.09 t/ha) with I_2, while the lowest grain yield (2.69 t/ ha) was observed from I_3 and it was statistically similar with I_1 (2.60 t/ha). Meena *et al.* (1998) reported that wheat grain yield was the highest with 2 irrigations (2.57 t/ha) in 1993 and (2.64 t/ha) at flower and/or crown root initiation stages (Table 4.7). Wheat is sown in November to ensure optimal crop growth and avoid high temperature and after that if wheat is sown in the field, it faces high range of temperature for its growth and development as well as yield potential.



I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Figure 4.23: Effect of water stress condition on yield of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Table 4.7 Effect of water stress on yield parameters of wheat

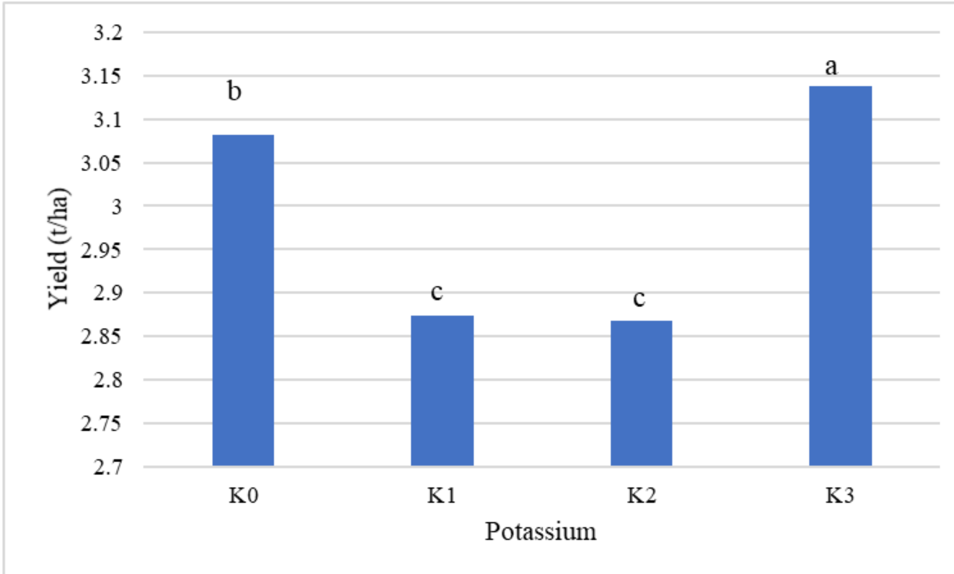
Irrigation	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological Yield (t ha^{-1})	Harvest Index (%)
I_0	3.60a	2.80a	5.40ab	51.46b
I_1	2.60b	2.25b	5.80a	60.10a
I_2	3.09ab	1.80bc	4.99ab	60.10a
I_3	2.69b	1.60c	4.20b	60.03a
LSD (0.05)	**0.57**	**0.35**	**0.40**	**8.56**
CV%	**2.8**	**17.08**	**5.75**	**6.70**

I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Different letters indicates treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.12.2 Effect of different doses of potassium fertilizer on yield of wheat

Different levels of potassium fertilizer showed statistically significant variation in terms of grain yield of wheat due to (Figure 4.24) the application of different level of K. The highest grain yield (3.14 t/ha) was observed from K_3 followed by (3.08 t/ha) in K_0 treatment, which were statistically different from all other treatment (Table 4.8). The lowest grain yield (2.86 t/ha) was found in K_2, which was statistically similar to K_1 (2.87 t/ha) but significantly different from others. Potassium is reported to improve water relations as well as productivity of different crops under water stress condition (Johnson, 1983, Islam *et al*., 2004). Saren and Jana (2008) found that application of 50 kg K/ha as top dressing after irrigation gave the highest grains yields.



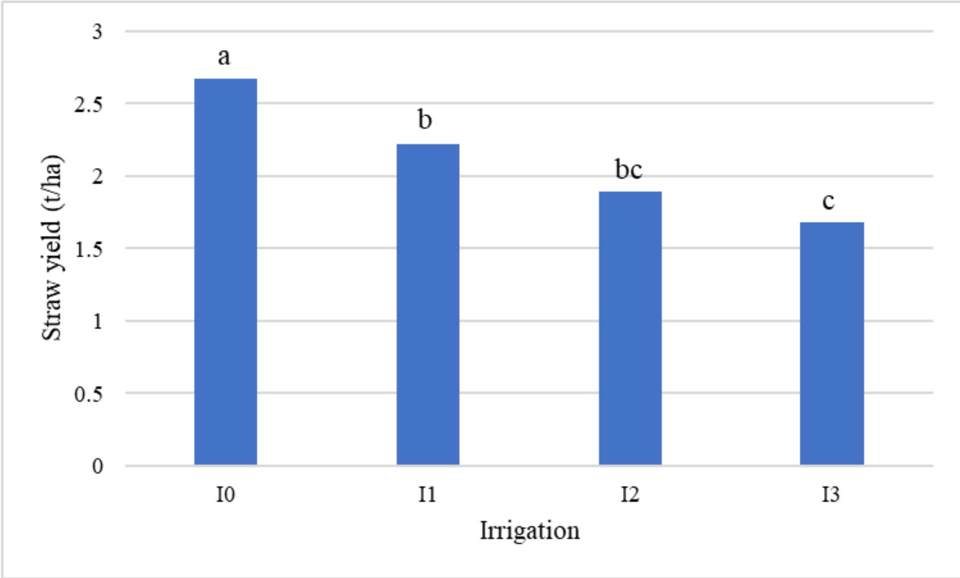
K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Figure 4.24: Effect of different doses of potassium fertilizer on yield of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.13 Straw yield

4.1.1.13.1 Effect of water stress condition on straw yield

Straw yield of wheat showed statistically significant variation due to different levels of irrigation (Figure 4.25). The highest straw yield (2.80 t/ha) was observed from I_0 followed by (2.25 t/ha) in I_1 which was statistically similar (1.80 t/ha) to I_2. The lowest straw yield (1.60 t/ha) was observed from I_3 which was significantly different from others (Table 4.7).



I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Figure 4.25: Effect of water stress condition on straw yield of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Table 4.8 Effect of different doses of potassium on yield parameters of wheat

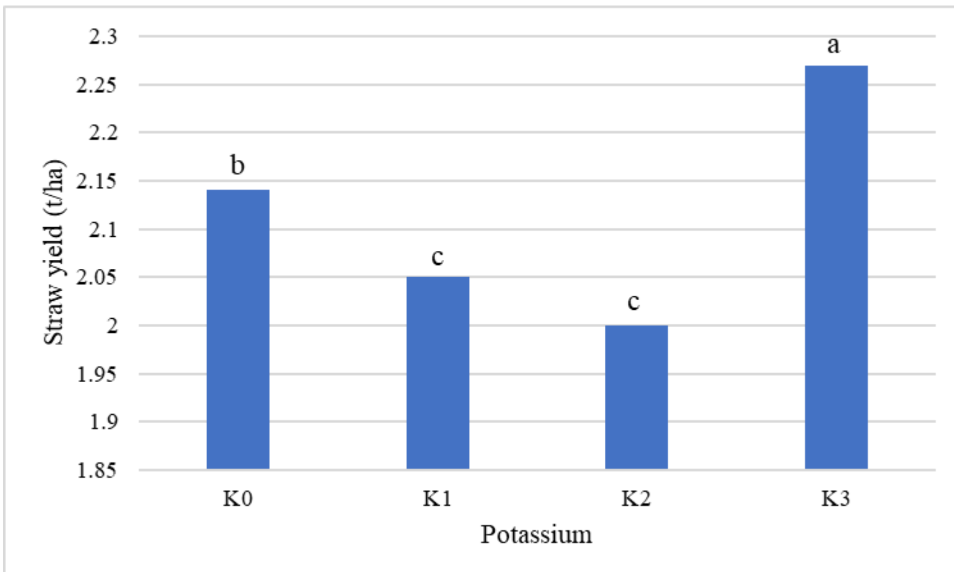
Potassium	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest Index (%)
K_0	3.08b	2.14b	5.21a	51.46a
K_1	2.87c	2.05c	4.92b	60.10a
K_2	2.86c	2.0c	4.88b	60.10a
K_3	3.14a	2.27a	5.41a	60.03a
LSD $_{(0.05)}$	**0.057**	**0.81**	**0.32**	**8.88**
CV%	**2.04**	**3.45**	**6.87**	**3.56**

K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Different letters indicates treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.13.2 Effect of different doses of potassium fertilizer on straw yield

Statistically significant variation was observed in terms of straw yield of wheat due to different levels of potassium fertilizer (Figure 4.26). The highest straw yield (2.27 t/ha) was observed from K_3 treatment (Table 4.8). Again, the lowest straw yield (2.0 t/ha) was found in K_2 which was statistically similar (2.05 t/ha) with K_1. Saren and Jana (2008) found that application of 50 kg K/ha as top dressing after irrigation gave the highest straw yields.



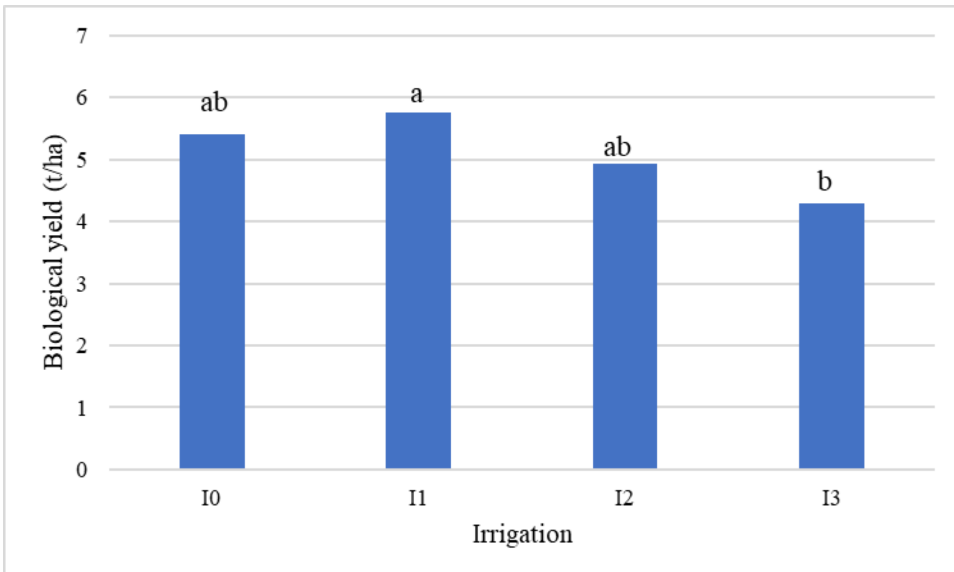
K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Figure 4.26: Effect of different doses of potassium fertilizer on straw yield of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.14 Biological yield

4.1.1.14.1 Effect of water stress condition on biological yield

Biological yield of wheat showed statistically significant variation due to different levels of irrigation (Figure 4.27). The highest biological yield (5.80 t/ha) was observed from I_1, followed I_0 (5.4 t/ha) and I_2 (4.99 t/ha), while the lowest biological yield (4.20 t/ha) was observed from I_3 (Table 4.7). Gupta *et al.*, (2001) reported that biological yield decreased to a greater extent when water stress was imposed at the anthesis stage.

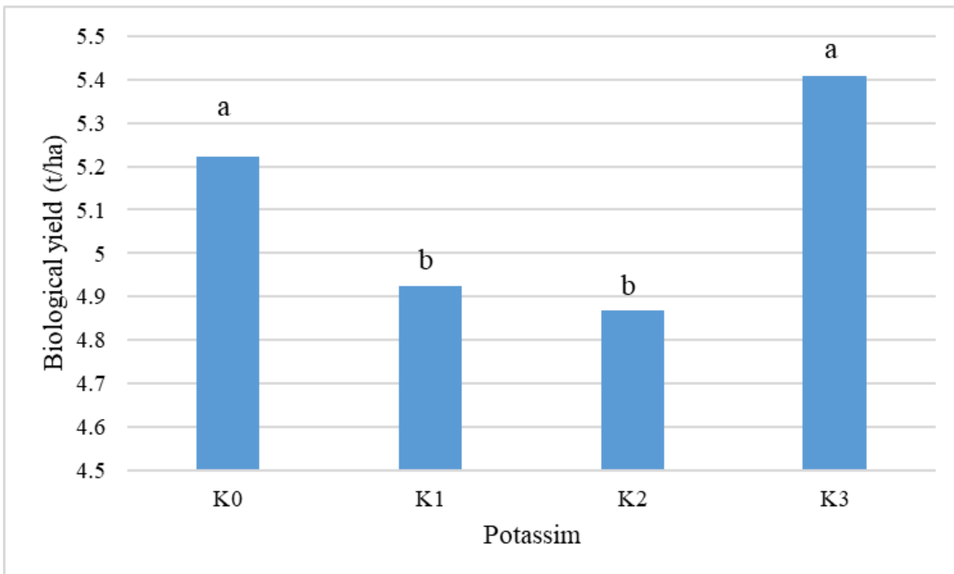


I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Figure 4.27: Effect of water stress condition on biological yield of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.14.2 Effect of different doses of potassium fertilizer on biological yield

Statistically significant variation was observed in terms of biological yield of wheat due to different levels of potassium fertilizer (Figure 4.28). The highest biological yield (5.41 t/ha) was observed from K_3 treatment (Table 4.8), which was statistically similar (5.21 t/ha) with K_0. The lowest biological yield (4.88 t/ha) was found in K_2.



K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

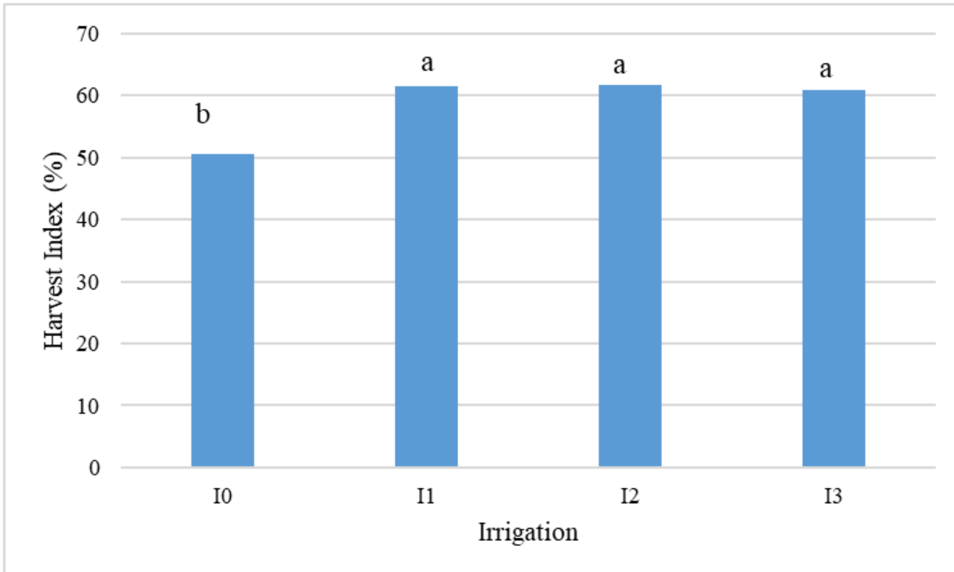
Figure 4.28: Effect of different doses of potassium fertilizer on biological yield of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.15 Harvest index

4.1.1.15.1 Effect of water stress condition on harvest index

Harvest index of wheat showed statistically non-significant variation due to different levels of irrigation (Figure 4.29). The highest harvest index (60.1%) was observed from I_1 and I_2 (Table 4.7). whereas the lowest harvest index (51.0%) was found from I_0. Gupta *et al.*,

(2001) reported that harvest index decreased to a greater extent when water stress was imposed at the anthesis stage.

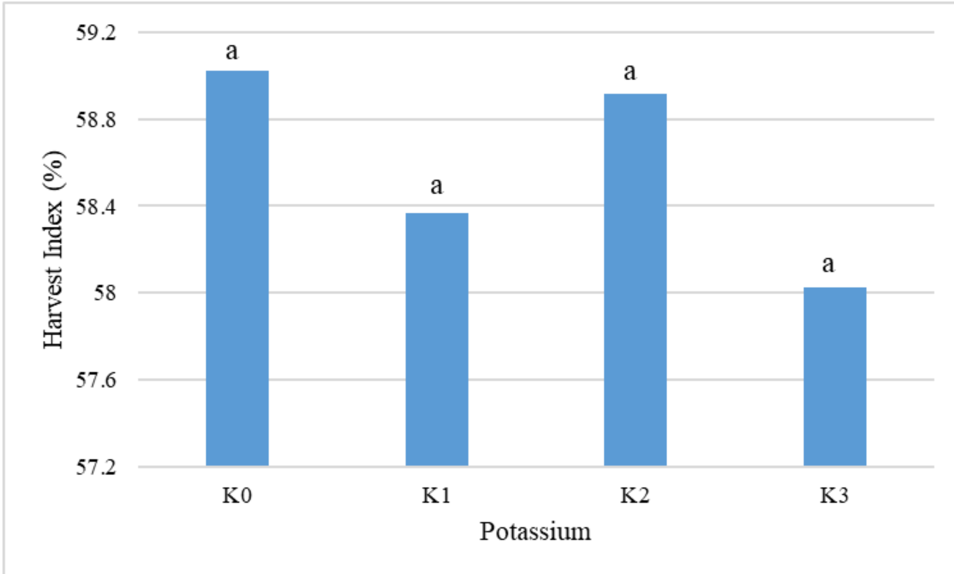


I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Figure 4.29: Effect of water stress condition on harvest index of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.15.2 Effect of different doses of potassium fertilizer on harvest index

Statistically significant variation was observed in terms of harvest index of wheat due to different levels of potassium fertilizer (Figure 4.30). The highest harvest index (59 %) was observed from K_2 treatment (Table 4.8), which was statistically similar with K_0, while the lowest harvest index (58 %) was found in K_3.



K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Figure 4.30: Effect of different doses of potassium fertilizer on harvest index of wheat. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

4.1.1.15.3 Interaction of water stress condition and potassium fertilizer on different yield parameters of wheat

Statistically significant variation was observed due to the interaction effect of different levels of irrigation and potassium fertilizer on grain yield (Table 4.9). The highest grain yield (4.04 t/ha) was observed from I_0K_3, while the lowest grain yield (2.29 t/ha) was recorded from I_0K_1. Interaction effect of different levels of irrigation and potassium fertilizer showed significant differences on straw yield (Table 4.9). The highest straw yield (3.62 t/ha) was observed from I_0K_0, while the lowest straw yield (1.59 t/ha) was recorded from I_2K_0. Interaction effect of different levels of irrigation and potassium fertilizer showed significant differences on biological yield (Table 4.9). The highest biological yield (7.80 t/ha) was observed from I_0K_3, while the lowest biological yield (4.28 t/ha) was recorded from I_3K_0 and I_3K_1.

Interaction effect of different levels of irrigation and potassium fertilizer showed significant differences on harvest index (Table 4.3). The highest harvest index 64.91% was observed from I_2K_1, while the lowest harvest index (51.01%) was recorded from I_0K_0.

Table 4.9. Interaction of water stress condition and potassium fertilizer on different yield parameters of wheat

Interaction	Yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest Index (%)
$I_0 \times K_0$	3.77a-c	3.62a	5.3c	51.01cd
$I_0 \times K_1$	2.29e	2.18b-d	4.47d	51.23cd
$I_0 \times K_2$	2.29e	2.18b-d	4.47d	51.23cd
$I_0 \times K_3$	4.04a	2.68b	7.80a	49.43d
$I_1 \times K_0$	3.13a-c	1.77cd	4.9cd	63.87a
$I_1 \times K_1$	3.19a-e	2.20b-d	5.39c	59.18ab
$I_1 \times K_2$	3.80ab	2.41bc	6.21b	61.19ab
$I_1 \times K_3$	2.66b-e	2.47bc	6.51b	62.05ab
$I_2 \times K_0$	2.71b-e	1.59d	4.3d	63.02a
$I_2 \times K_1$	3.59a-d	1.94cd	5.53c	64.91a
$I_2 \times K_2$	2.64c-e	1.79cd	4.43d	59.59ab
$I_2 \times K_3$	3.22a-e	2.26b-d	5.48c	58.75ab
$I_3 \times K_0$	2.71b-e	1.57d	4.28d	63.31a
$I_3 \times K_1$	2.41e	1.87cd	4.28d	56.30bc
$I_3 \times K_2$	2.73b-e	1.63d	4.36d	62.61ab
$I_3 \times K_3$	2.66b-e	1.66d	4.32d	61.57ab
LSD (0.05)	**0.25**	**1.26**	**1.69**	**0.80**
CV%	**6.98**	**21.82**	**11.83**	**18.35**

Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

I_0 = Control (normal irrigation),
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

4.1.1.16 Soil chemical properties in post harvest soil of wheat crop field

4.1.1.17 Effect of recommended fertilizers on chemical properties in post harvest soil of wheat crop field

Effect on soil pH and soil organic carbon (SOC)

Soil pH

The availability of soil nutrient is greatly influenced by soil pH. There was no significant change in pH of post harvest soil due to application of recommended fertilizers where pH varied from 5.6 to 5.8 (Table 4.10) and compared to initial soil pH 5.8

Soil organic carbon

Soil organic carbon influences the nutrient supply and water holding capacity. There was no significant change in soil organic carbon (SOC) of postharvest soil due to application of recommended fertilizers where SOC varied from 0.60 % to 0.68 % in (Table 4.10) and compared to initial soil organic carbon content 0.62 %.

Effect of NPKS nutrients of Soil

Total nitrogen content in postharvest soil showed no significant variation due to recommended fertilizers where nitrogen content varied from 0.059 % to 0.065 % (Table 4.10). Available phosphorus content in postharvest soil was non- significant application of recommended fertilizers. The result varied from 13.45 ppm to 14.91 ppm. (Table 4.10)

Table 4.10 Effect of water stress condition of soil chemical properties in post harvest soil of the experimental crop field of wheat

Irrigation	pH	Organic carbon (%)	Total N (%)	Available P (ppm)	Exchangeable K (meq 100^{-1}) g)	Available S (ppm)
I_0	5.6	0.62b	0.060b	14.19a	0.13a	13.45a
I_1	5.6	0.61b	0.062b	14.37a	0.13a	12.21a
I_2	5.7	0.63b	0.061b	14.54a	0.14a	13.65a
I_3	5.8	0.65a	0.063a	14.77a	0.14a	13.86a
LSD $_{(0.05)}$	**-**	**1.12**	**0.15**	**1.34**	**0.24**	**2.16**
CV%	**-**	**7.56**	**11.45**	**6.09**	**8.12**	**5.34**

In a column, figures having similar letter(s) do not differ significantly

I_0 = Control,
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

Table 4.11 Effect of recommended fertilizer on chemical properties in post harvest soil of the experimental crop field of wheat

Fertilizer	pH	Organic carbon (%)	Total N (%)	Available P (ppm)	Exchangeable K (meq 100^{-1} g)	Available S (ppm)
K_0	5.6	0.62b	0.061a	13.19b	0.12b	15.45a
K_1	5.7	0.63b	0.064a	14.37a	0.14a	11.21b
K_2	5.7	0.63b	0.061a	12.54b	0.15a	14.65a
K_3	5.8	0.68a	0.062a	15.77a	0.14a	13.86a
LSD $_{(0.05)}$	**-**	**1.43**	**0.23**	**1.16**	**0.15**	**1.21**
CV%	**-**	**6.09**	**5.65**	**14.34**	**11.67**	**8.7**

In a column, figures having similar letter(s) do not differ significantly

K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Table 4.12 Interaction effect of water stress condition and potassium fertilizer on soil chemical properties of crop field of wheat

Interaction Irrigation x Fertilizers	pH	Organic Carbon (%)	Total N (%)	Available P (ppm)	Exchangeable K (meq 100^{-1} g)	Available S (ppm)
$I_0 \times K_0$	5.6	0.59d	0.090ab	15.45bc	0.22e	14.16c
$I_0 \times K_1$	5.7	0.64bc	0.080ab	14.42g	0.24b	13.27de
$I_0 \times K_2$	5.7	0.60c	0.080ab	14.73f	0.23d	14.77b
$I_0 \times K_3$	5.7	0.66b	0.110a	15.51b	0.36a	14.77b
$I_1 \times K_0$	5.6	0.58d	0.060d	14.45g	0.23b	13.67cd
$I_1 \times K_1$	5.6	0.60d	0.061c	15.03c	0.23c	12.86ef
$I_1 \times K_2$	5.6	0.59d	0.060d	14.75f	0.25c	13.75cd
$I_1 \times K_3$	5.8	0.65b	0.062c	15.52b	0.35a	14.80ab
$I_2 \times K_0$	5.6	0.60d	0.061c	14.11h	0.24d	11.92h
$I_2 \times K_1$	5.8	0.68a	0.061c	14.72f	0.21a	12.77g
$I_2 \times K_2$	5.7	0.62c	0.062c	14.50g	0.24ab	12.95ef
$I_2 \times K_3$	5.9	0.67a	0.074ab	15.95a	0.33a	14.89a
$I_3 \times K_0$	5.6	0.68a	0.061c	15.02c	0.22d	11.25hi
$I_3 \times K_1$	5.6	0.69a	0.055ab	14.45g	0.25c	12.88de
$I_3 \times K_2$	5.6	0.66b	0.063c	15.40d	0.29b	12.95d
$I_3 \times K_3$	5.8	0.68a	0.10a	15.24e	0.33a	14.95a
LSD (0.05)	-	0.56	0.12	2.13	0.23	4.5
CV%	-	6.1	13.53	10.78	5.48	1.13

In a column, figures having similar letter(s) do not differ significantly
I_0 = Control,
I_1 = Water stress at vegetative stage,
I_2 = Water stress at flower initiation stage,
I_3 = Water stress at milking stages.

K_0 = 0 kg K/ha
K_1 = 60 kg K/ha
K_2 = 90 kg K/ha
K_3 = 120 kg K/ha

Exchangeable K content in post harvest soil also non-significant due to application of recommended fertilizers, the result varied from 0.130 meq 100^{-1}g to 0.145 meq 100^{-1}g (Table 4.12).

Du e to application of recommended fertilizers in wheat field available S content of post harvest soil was insignificant. Available S content varied from 11.92 ppm to 14.97 ppm

(Table 4.12). Water stress affected significantly dry matter accumulation in leaf, stem, spikes and roots. The uptake of N, P and K was lowered by the water stress. Consequently, most of the yield contributing characters as well as gain yield was reduced substantially. Higher level of K improved the dry matter production in different plant parts. Yield and yield contributing characters of wheat where also improved due to high level of K application irrespective level of soil moisture. Uptake of K, P and N was also enhanced with the increasing levels of K especially under water conditions. So, it was concluded that application of high levels of potassium (greater than recommended dose) might mitigate the deleterious effects of water stress on wheat productivity by Baque *et al*., (2006).

4.2 Experiment 2: Integrated nutrient management for boro rice to investigate potassium balance in soil.

The experiment was conducted to investigate the effects of integrated nutrient management of potassium balance in soil on the growth and yield contributing characters of boro rice. The results of the present study have been presented and discussed in this chapter under the following heading.

4.2.1 Yield attributes and yields of rice

4.2.1.1 Plant height of rice

4.2.1.1.1 Effect of different combination of potassium treatment on plant height

Plant height is an important agronomic trait of rice that directly affects the yield of this crop. Plant height varied significantly due to different combination of potassium treatments on boro rice. Plant height ranged from (88.1cm to 100 cm) in different potassium combined applications. The tallest plant (100.0 cm) was produced in T_2 {Fertilizer recommended dose for BRRI dhan28 (100% MoP)}, which was statistically similar with the treatment T_3, T_5 and T_7 (96.5 cm, 96.5 cm and 96.6 cm) treatments. The lowest plant height (88.1 cm) was produced under control treatment, which was significantly different from others but statistically similar with T_4 and T_{11} treatments (90.5 cm & 90.6 cm). The increase in plant height due to application of increased level of fertilizer and manure might be associated with stimulating effect of nitrogen on various physiological processes including cell division and cell elongation of the plant. In general, plant height increased with the increasing level potassium with organic matter.

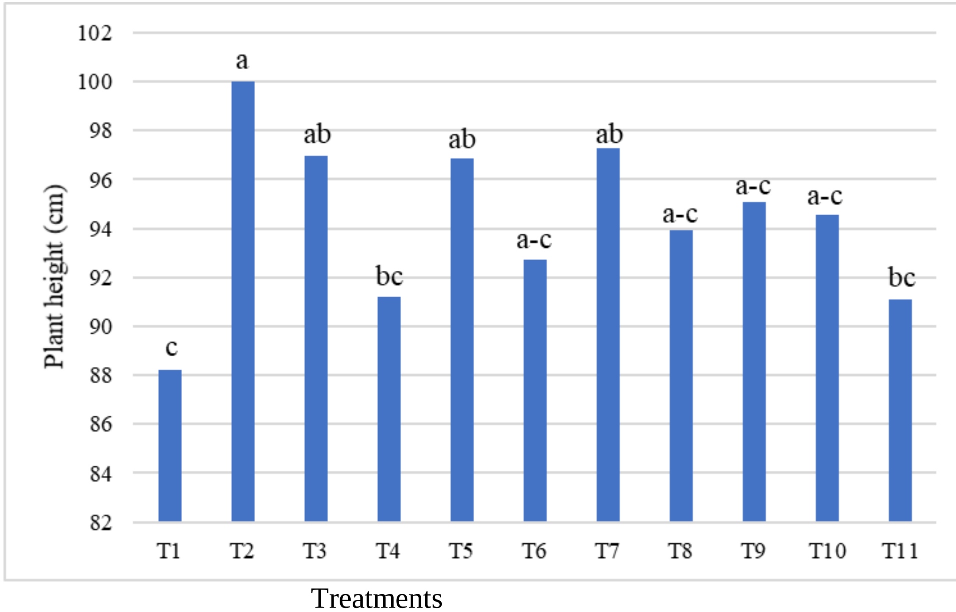


Figure 4.31. Effect of different combination of potassium treatment on plant height of rice. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

T_1 = Control
T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

4.2.1.2 Number of total tillers per plant

4.2.1.2.1 Effect of different combination of potassium treatment on number of total tillers per plant

Total number of tillers per hill was influenced by different combination of potassium treatments (Figure 4.32). The maximum number of total tillers hill^{-1} (26) was produced from T_9 {75% K supplement by cow dung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP} which was statistically similar with T_{10} and T_{11} (26). Minimum number of total tillers hill^{-1} (16.5) was produced form T_8 treatment which was significantly different from other treatments except T_4 and T_2. The progressive improvement in the formation of tillers might be due to effect of fertilizer and manure which was also reported by Mirzeo and Narse (1989).

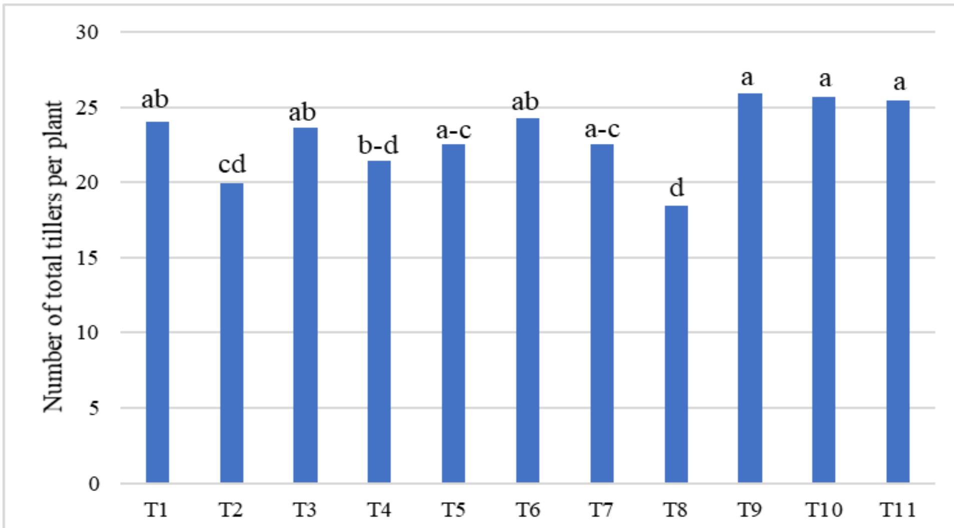


Figure 4.32. Effect of different combination of potassium treatment on number of total tillers per plant of rice. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

T_1 = Control
T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 t/ha) from MoP
T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

4.2.1.3 Number of effective tillers per plant

4.2.1.3.1 Effect of different combination of potassium treatment on number of effective tillers per plant

Adequate number of effective tillers exerts a role in producing panicle number and the spikelet number. Number of effective tillers per hill was statistically influenced by different combination of potassium treatment (Figure 4.33). The maximum number of total tillers hill^{-1} (20.25) was produced from T_9 (75% K supplement by cow dung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP) which was statistically similar with all other treatments except T_8. Minimum number of total tillers hill^{-1} (17) was observed form T_8 treatment and it was significantly different from all the other treatments.

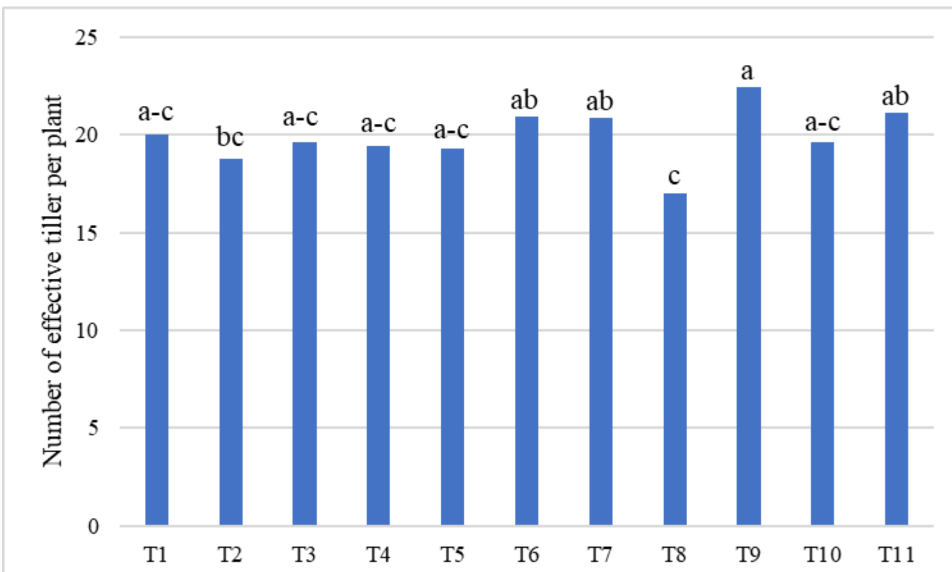


Figure 4.33: Effect of different combination of potassium treatment on number of effective tillers per plant of rice. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

T_1 = Control
T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP

T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

4.2.1.4 Number of non-effective tillers per plant

4.2.1.4.1 Effect of different combination of potassium treatment on number of non-effective tillers per plant

Higher number of non-effective tillers can lead to lower grain and ultimately reduced yield. Number of non-effective tillers varied due to different combination of potassium treatment. (Figure 4.34). The maximum total number of non-effective tillers (6.1) was produced from T_{10} (75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MOP) which was statistically similar with all other treatments except T_8. Minimum total number of non-effective tillers (1.2) was observed form T_8 treatment and it was significantly different from all the other treatments.

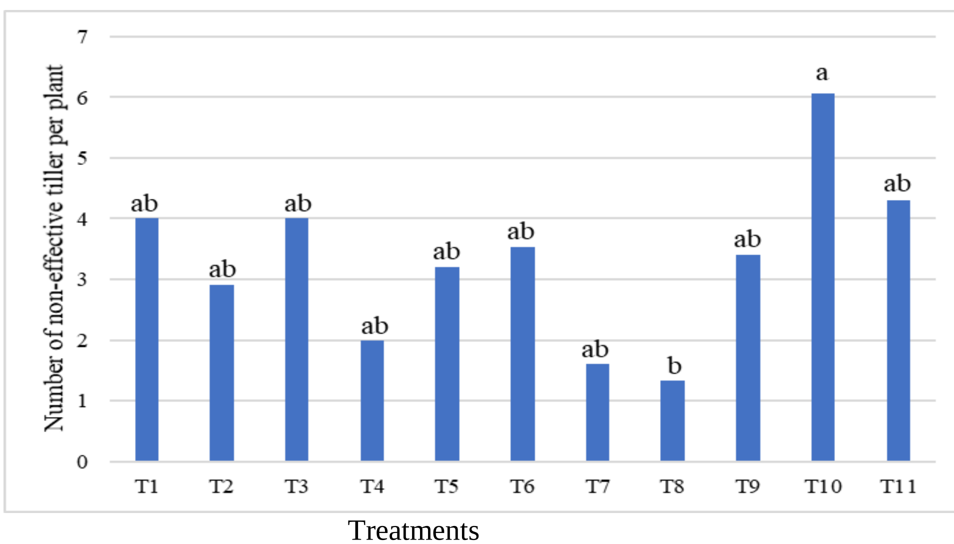


Figure 4.34. Effect of different combination of potassium treatment on number of non-effective tillers per plant of rice. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

T_1 = Control
T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

Table 4.13. Effect of integrated nutrient management of potassium balance on plant characteristics of boro rice

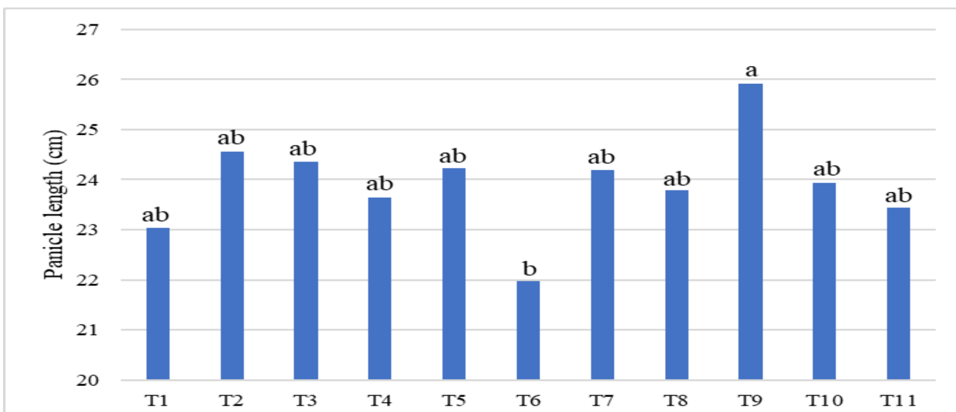
Treatments	Plant height (cm)	Total no. of tillers hill^{-1}	Effective tillers hill^{-1} (nos)	Non-effective tillers hill^{-1} (nos)	Flag leaf length (cm)
T_1	88.2c	24ab	20abc	4ab	26.371ab
T_2	100.03a	19.9cd	18.8bc	2.9ab	27.626ab
T_3	96.99ab	23.6ab	19.6abc	4ab	27.854ab
T_4	91.22bc	21.4bcd	19.4abc	2ab	27.103ab
T_5	96.87ab	22.5abc	19.3abc	3.2ab	26.5ab
T_6	92.71abc	24.267ab	20.935ab	3.5333ab	25.277b
T_7	97.26ab	22.5abc	20.9ab	1.6ab	28.68ab
T_8	93.91abc	18.4d	17c	1.3333b	27.353ab
T_9	95.06abc	25867a	22.467a	3.4ab	28.677ab
T_{10}	94.53abc	25.66a	19,6abc	6.0667a	29.837a
T_{11}	91.07bc	25.4a	21.1b	4.3ab	26.64ab
LSD (0.05)	**5.51**	**3.86**	**1.8**	**2.1**	**4.01**
CV%	**5.63**	**11.43**	**2.24**	**18.27**	**12.19**

Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.
T_1 = Control
T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

4.2.1.5 Panicle length

4.2.1.5.1 Effect of different combination of potassium treatment on panicle length

Panicle length is usually measured as a yield-related trait. Panicle length was statistically affected by different combinations of potassium treatments (Figure 4.35). Longest (25.9 cm) panicle was produced from T_9 treatment (75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP), which was statistically similar with all other treatments except T_6. Lowest (22 cm) panicle length was produced form T_6 treatment (50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP) and it was significantly different from all the other treatments.



Treatments

Figure 4.35: Effect of different combination of potassium treatment on panicle length of rice. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

T_1 = Control
T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

Huda *et al*., (2016) described that all yield contributing characters like plant height, number of tillers, panicle length significantly responded to different levels of applied potassium. Similarly, Bahmaniar et al., (2007) found that potassium application increased plant height, number of tiller, length of panicle, number of grains/ panicle and grain yield of rice.

4.2.1.6 Length of flag leaf

4.2.1.6.1 Effect of different combination of potassium treatment on length of flag leaf

Flag leaf is the most essential organ for photosynthesis in rice and it affects photosynthesis to a certain extent, thereby influencing rice production. Length of flag leaf was affected by different combinations of potassium treatments (Figure 4.36). Longest (29.9 cm) flag leaf was produced from T_{10} treatment (75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP), which was statistically similar with all other treatments except T_6. Lowest (25.2 cm) flag leaf length was produced form T_6 treatment (50% K supplement by cow dung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP) and it was significantly different from all the other treatments.

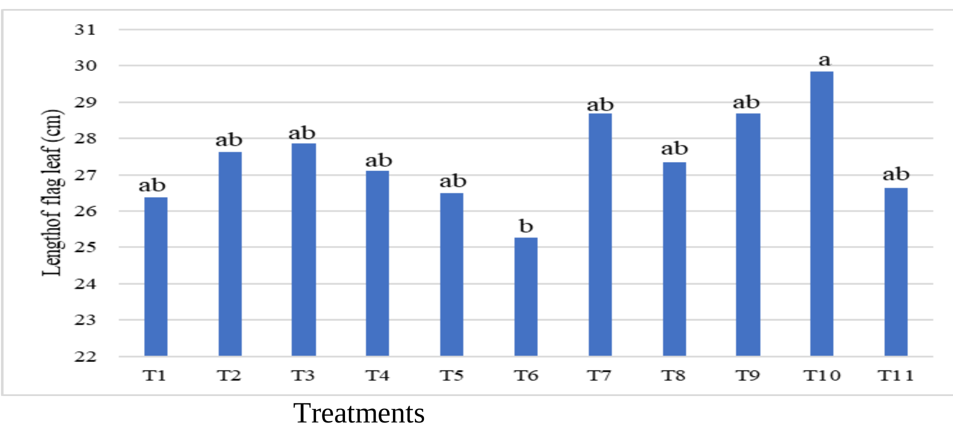


Figure 4.36: Effect of different combination of potassium treatment on length of flag leaf of rice. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

T_1 = Control

T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)

T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP

T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP

T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP

T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP

T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP

T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

4.2.1.7 Filled grains per panicle

4.2.1.7.1 Effect of different combination of potassium treatment on filled grains per panicle

There was a statistical variation in number of filled grains panicle^{-1} due to different combination of potassium treatment. Results showed that highest number of filled grains panicle^{-1} was obtained (193.7) from T_8 treatment {50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP}, which was statistically similar with treatment T_2 and T_{10} (174 and 171.3) but significantly different from T_1 (164). The lowest number of filled grains panicle^{-1} (124.4 was found from T_6 and it was statistically similar with T_5, T_9 and T_{11} (132.7, 134 and 128) treatment. Gradual increase in the supply of potassium contributed in more formation of filler grain, potassium form combination of vermicompost and MoP equally resulted into highest filled grain.

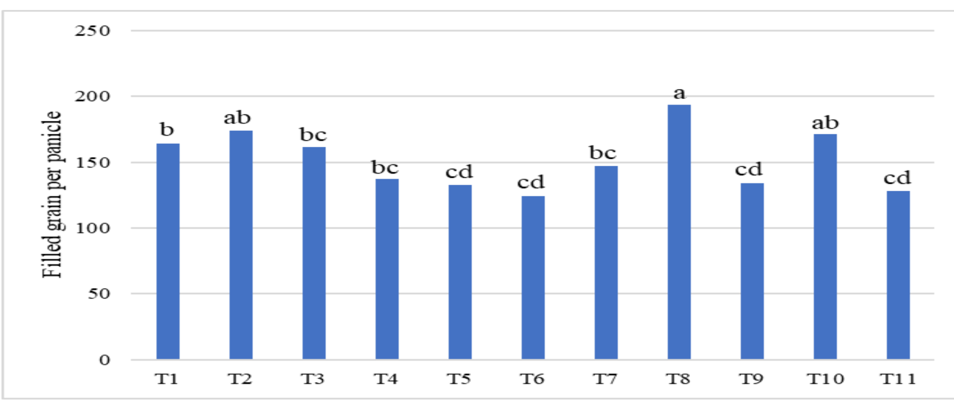


Figure 4.37. Effect of different combination of potassium treatment on filled grain per panicle of rice. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

T_1 = Control
T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP

T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

4.2.1.8 Unfilled grains per panicle

4.2.1.8.1 Effect of different combination of potassium treatment on unfilled grains per panicle

Among the traits made, number of unfilled grains panicle^{-1} plays a vital role in yield reduction. Number of unfilled grains panicle^{-1} was statistically influenced from the different combination of potassium levels (Figure 4.38). The highest number of unfilled grains panicle^{-1} was obtained (10) from T_6 treatment {50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP}, followed by T_3 (8) which were statistically similar to each other. The lowest number of unfilled grains panicle^{-1} (6) was found from T_2 {Fertilizer recommended dose for BRRI dhan28 (100% MoP)} treatment.

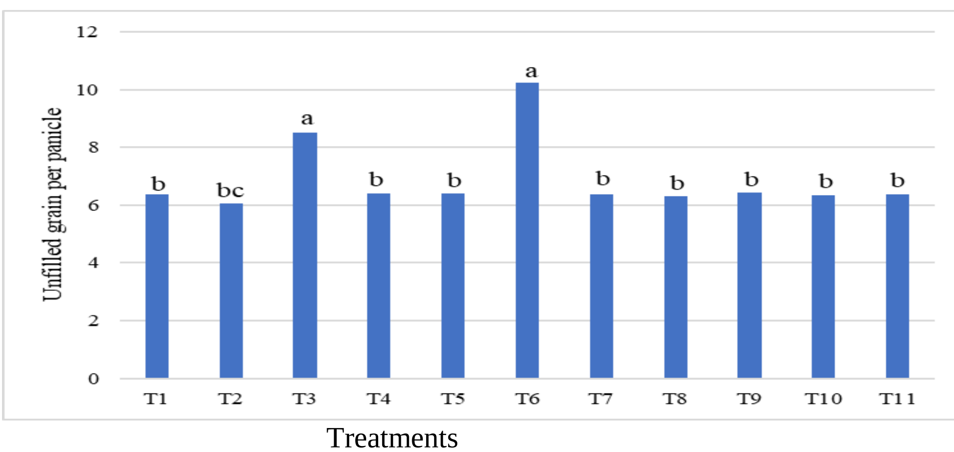


Figure 4.38: Effect of different combination of potassium treatment on unfilled grain per panicle of rice. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

T_1 = Control
T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP

T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

4.2.1.9 Total grains per panicle

4.2.1.9.1 Effect of different combination of potassium treatment on total grains per panicle

There was a statistical variation in total grains panicle^{-1} due to different combination of potassium treatment. Results showed that highest number of total grains panicle^{-1} was obtained (200) from T_8 treatment {50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP}, followed by treatment T_2 and T_{10} (180 and 177.64) and they were statistically similar with each other but significantly different from T_8 . The lowest number of filled grains panicle^{-1} (134.38) was found from T_{11} and it was statistically similar to T_6 (134.63) treatment.

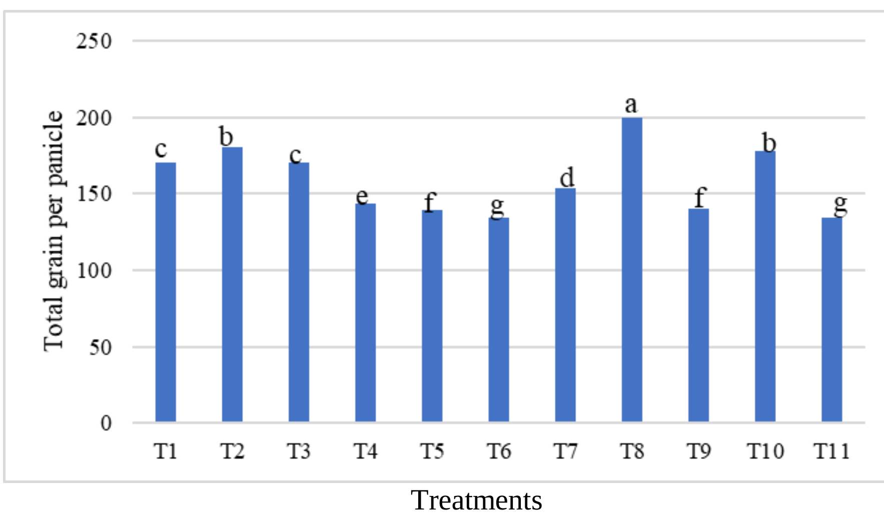


Figure 4.39: Effect of different combination of potassium treatment on total grain per panicle of rice. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

T_1 = Control

T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg Kha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

Table 4.14. Effect of integrated nutrient management of potassium balance on growth of reproductive stage of boro rice

Treatments	Panicle length (cm)	Filled grains panicle^{-1} (nos)	Unfilled grains panicle^{-1} (nos)	Number of total grains per panicle	1000 grains weight (g)
T_1	23.029ab	164b	6.36b	170.3c	0.2267ab
T_2	24.55ab	174ab	6.04bc	180b	0.2267ab
T_3	24.363ab	161.7bc	8.5a	170.2c	0.2267ab
T_4	23.647ab	137.3bc	6b	143.7e	0.23ab
T_5	24.221ab	132.7cd	6.4b	139.09f	0.2267ab
T_6	21.98b	124.4d	10.25a	134.63g	0.2267ab
T_7	24.2ab	147.3bc	6.38b	153.68d	0.2333ab
T_8	23.78ab	193.7a	6.3b	200a	0.2367a
T_9	25.917a	134cd	6.42b	140.42f	0.2333ab
T_{10}	23.943ab	171.3ab	6.34b	177.64b	0.2233b
T_{11}	23.44ab	128cd	6.38b	134.38g	0.2333ab
LSD (0.05)	**1.02**	**21.5**	**3.8**	**19.0**	**.31**
CV%	**12.87**	**2.98**	**6.89**	**15.18**	**11.57**

Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.
T_1= Control
T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost 5.62 t/ha + 25% K (18.75 kg K/ha) from MoP

4.2.1.10 1000 grains weight

4.2.1.10.1 Effect of different combination of potassium treatment on 1000- grains weight

Significant variation was observed in the case of 1000 grains weight due to different combination of potassium treatment (Figure 4.40). The highest number of 1000, grains weight (0.2367 kg) was found in T_8 treatment {50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP}. On the other hand, lowest number of 1000 grains weight (0.2233 kg) was observed in the T_{10} treatment {75% K supplement by poultry liter (6.60 t/ha)+25% K (18.75 kg K/ha) from MoP}. All other treatments were statistically similar to each other; only T_8 and T_{10} were significantly differed. Results indicate that different combination of potassium dose from various source had no significant effect on 1000-grains weight of rice.

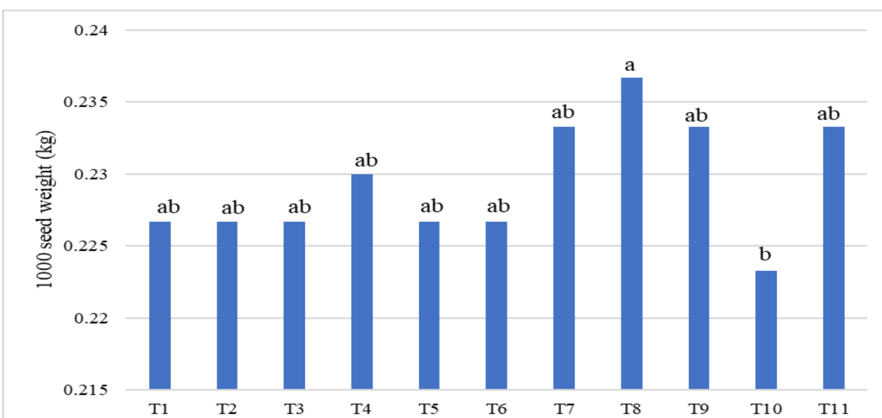


Figure 4.40. Effect of different combination of potassium treatment on 1000 grains weight of rice. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

T_1 = Control
T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP

T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

4.2.1.11 Grain yield

4.2.1.11.1 Effect of different combination of potassium treatment

Grain yield affected significantly due to the levels of different potassium levels (Figure 4.41). The maximum grain yield (6.55 t ha^{-1}) was produced from T_7 treatment {50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP}, which was significantly different from the T_1 treatment {75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP} producing minimum grain yield (2.35 t ha^{-1}). All other treatments were statistically similar to each other. Results showed that different combination of potassium dose from various source had significant effect on yield of rice.

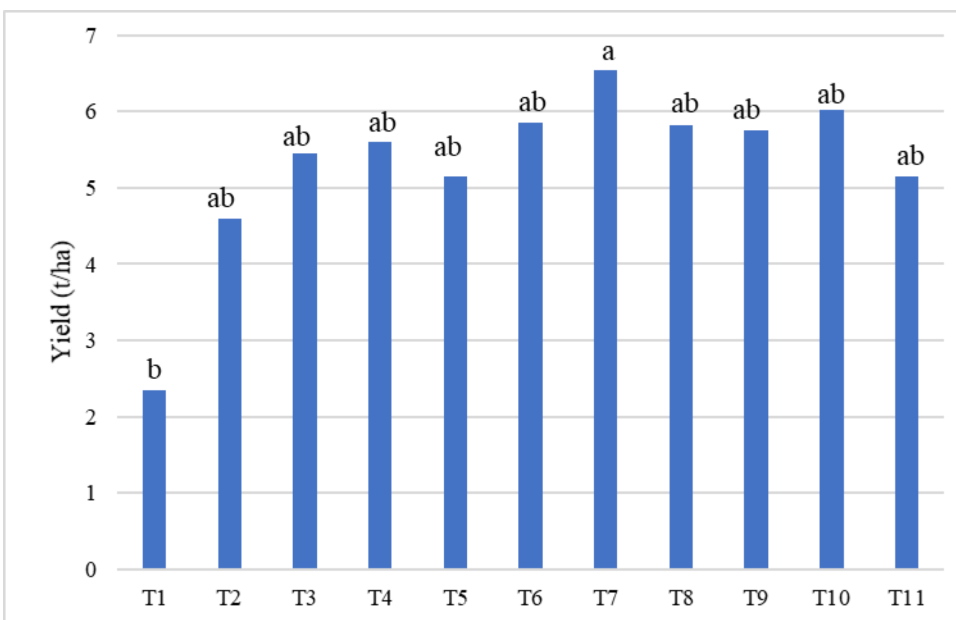


Figure 4.41. Effect of different combination of potassium treatment yield of rice. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

T_1 = Control
T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

4.2.1.12 Straw yield

4.2.1.12.1 Effect of different combination of potassium treatment straw yield

Results found from the (Figure 4.42) indicated that straw yield was significantly affected due to the levels of different potassium levels. The maximum straw yield (7.76 t ha^{-1}) was produced from treatment T_6. The minimum straw yield (4.99 t ha^{-1}) was observed from T_1.

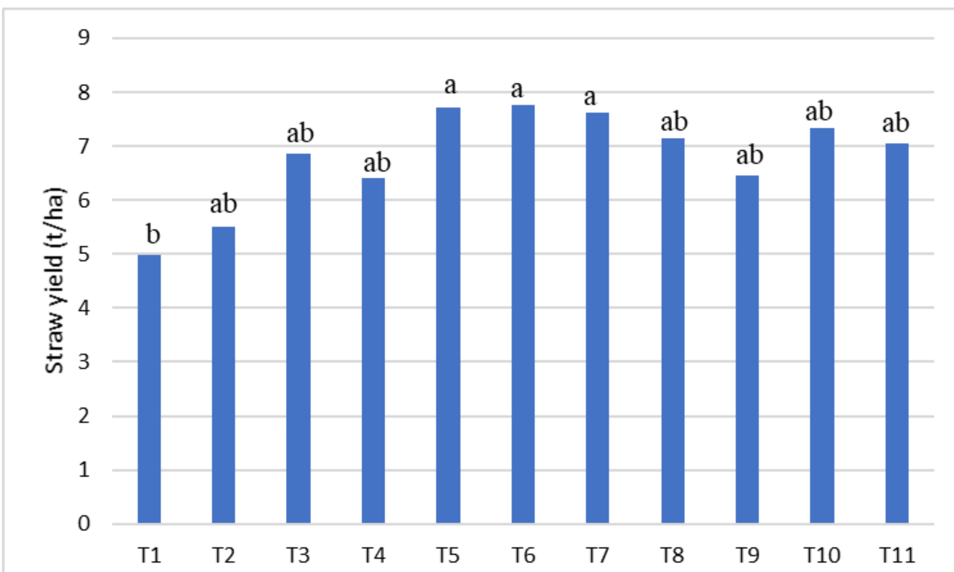


Figure 4.42 Effect of different combination of potassium treatment straw yield of rice. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

T_1 = Control
T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP

T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

4.2.1.13 Biological yield

4.2.1.13.1 Effect of different combination of potassium treatment biological yield

It was evident from the results (Figure 4.43) that biological yield was significantly affected by the levels of potassium. The maximum biological yield (14.18 t/ ha) was produced from T_7 treatment {50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP}. The minimum biological yield (7.34 t ha^{-1}) was observed from T_1 (control)

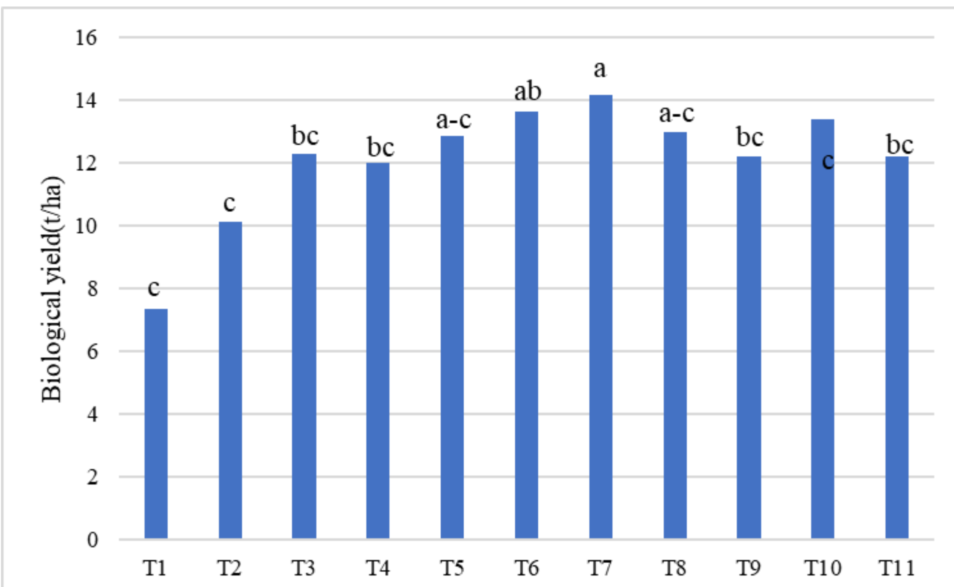


Figure 4.43: Effect of different combination of potassium treatment biological yield of rice. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

T_1 = Control
T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP

T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

4.2.1.14 Harvest Index

4.2.1.14.1 Effect of different combination of potassium treatment harvest index

Levels of potassium fertilizer had exerted significant variation on harvest index (Figure 4.44). The maximum harvest index (47.09%) was produced from T_8 treatment {50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP}. The minimum harvest index (32.02 %) was produce from T_1 treatment (control).

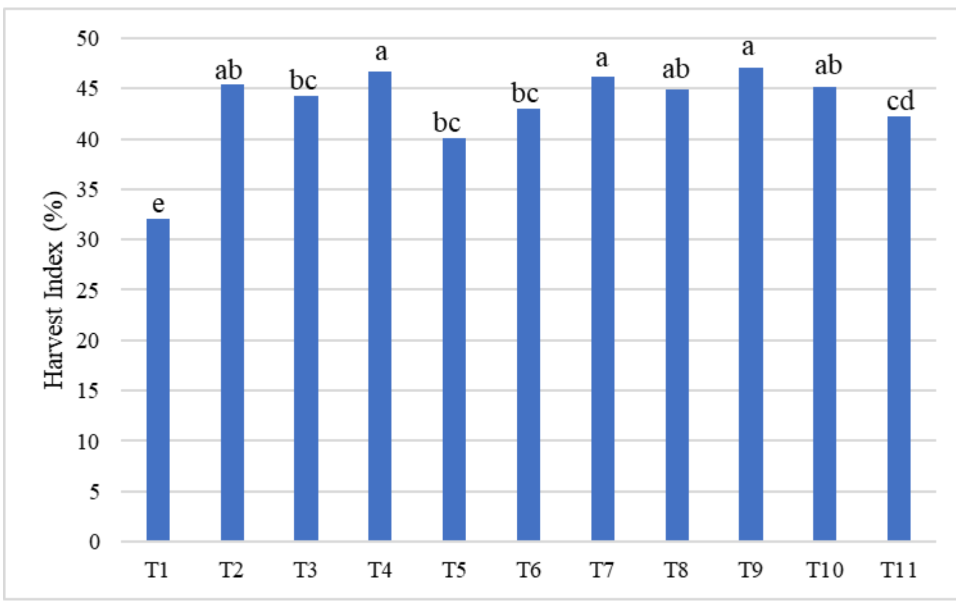


Figure 4.44: Effect of different combination of potassium treatment harvest index of rice. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

T_1 = Control
T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP

T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

Table 4.15 Effect of integrated nutrient management of potassium balance on yield of BRRI dhan28

Treatment	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)	Harvest index (%)
T_1	2.35f	4.99f	7.34f	32.02f
T_2	4.59e	5.51e	10.10e	45.45bc
T_3	5.45d	6.85cd	12.30cd	44.31bc
T_4	5.60cd	6.40de	12.00d	46.67ab
T_5	5.15d	7.72a	12.87bc	40.02e
T_6	5.85bc	7.76a	13.61b	42.98d
T_7	6.55a	7.63ab	14.18a	46.19ab
T_8	5.82bc	7.15bc	12.97bc	44.87bc
T_9	5.75cd	6.46cd	12.21cd	47.09a
T_{10}	6.03ab	7.34bc	13.37b	45.10bc
T_{11}	5.15d	7.05bc	12.2d	42.21d
LSD (0.05)	**0.57**	**0.73**	**1.4**	**1.9**
CV%	**6.54**	**2.65**	**11.54**	**14.65**

T_1 = Control
T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

4.2.2 Chemical properties in post harvest soil of rice crop field

Effect of BRRI dhan28 with other recommended fertilizers in post harvest soil in rice field

The application of different fertilizer and manure significantly influenced the pH, and N, P, K, S concentrations of post harvest soil.

Soil pH:

The highest pH of post harvest soil (6.4) was recorded from T_2 treatment. There was significant change in pH of post harvest soil of rice field due to application of different fertilizers along with other manures where pH varied from 6.0 to 6.4 (Table 4.16) and compare to initial soil pH 6.2 (Table 3.2).

Soil organic carbon

There was significant change in soil organic carbon (SOC) of post harvest soil of rice field due to effect of manures and different fertilizers where SOC varied from 0.73 to 0.78 (Table 4.16) and compare to initial soil 0.65 (Table 3.2).

Soil Nutrient NPKS

Total N content in post harvest soil of BRRI dhan28 showed no significant variation due to the effect of manures and different fertilizers where N content varied from 0.054 to 0.093% (Table 4.6). The highest total N content 0.093 was found in the treatment of T_8 which was statistically similar with treatment T_2 and T_6. The lowest N content was observed in the treatment T_1.

Available P content in post harvest soil of rice crop field showed significant variation due to application of manures and different fertilizers where P content varied from 9.95 to 24.08 ppm (Table 4.16). The highest P content 24.08 ppm was found in the treatment of T_8 which was statistically similar with treatment T_3, T_5, T_{10} and T_{11}. The lowest P content in postharvest soil 9.95 ppm was found in treatment of T_1.

Exchangeable K content in post harvest soil showed insignificant variation due to effect of manures and different fertilizers where K content varied 0.020 to 0.042 meq 100^{-1}g (Table 4.6)

Available S content in post harvest soil of rice crop field showed significant variation due to application of manures and different fertilizers where S content varied from 11.40 to 34.02 ppm (Table 4.16). The highest S content 34.02 ppm was found in the treatment of T_8 which was statistically similar with treatment T_4 and T_6. The lowest S content in postharvest soil 11.40 ppm was found in treatment of T_1.

Table 4.16 Effect of BRRI dhan28 with other recommended fertilizers on chemical properties of post harvested soil of rice filed

Treatments	pH	Organic carbon (%)	Total N (%)	Available P (ppm)	Exchangeable K (meq/100g)	Available S (ppm)
T_1	6.1	0.73ab	0.054c	9.95e	0.20e	11.40e
T_2	6.4	0.77a	0.091a	16.03cd	0.39a	19.75d
T_3	6.3	0.73ab	0.078ab	21.89ab	0.32bc	23.23bc
T_4	6.0	0.75ab	0.067bc	17.93c	0.37ab	33.38a
T_5	6.2	0.77a	0.062bc	22.14ab	0.42a	24.43b
T_6	6.1	0.75ab	0.089a	20.00bc	0.34ab	30.75ab
T_7	6.1	0.77a	0.072ab	19.29bc	0.26d	17.87de
T_8	6.0	0.75ab	0.093a	24.08a	0.42a	34.02a
T_9	6.1	0.77a	0.066bc	19.32bc	0.32bc	19.30d
T_{10}	6.2	0.78a	0.075b	22.7ab	0.40a	23.5bc
T_{11}	6.0	0.77	0.058c	21.90ab	0.25d	25.03b
LSD (0.05)	-	0.8	0.13	16.18	0.54	23.42
CV%	-	8.90	4.87	3.54	11.45	12.98

T_1 = Control
T_2 = Fertilizer recommended dose for BRRI dhan28 (100% MoP)
T_3 = 25% K supplement by cowdung (1.25 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_4 = 25% K supplement by poultry liter (2.20 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_5 = 25% K supplement by vermicompost (1.87 t/ha) + 75% K (56.25 kg K/ha) from MoP
T_6 = 50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_7 = 50% K supplement by poultry liter (4.40 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_8 = 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP
T_9 = 75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{10} = 75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP
T_{11} = 75% K supplement by vermicompost (5.62 t/ha) + 25% K (18.75 kg K/ha) from MoP

Experiment 3: Improving quality and shelf life of carrots by applying potassium in Soil.

The experiment was conducted to investigate the effect of different levels of potassium for improving quality and shelf life of carrots. Data on different parameters were analyzed statistically and the results have been presented in Figures and Tables. The results of the study have been presented and discussed in this chapter under the following headings.

4.3.1 Growth parameters of carrot

4.3.1.1 Plant height

Plant height of carrot was significantly influenced by different doses of potassium (Figure 4.45). The highest plant height was observed in K_4 treatment (67.47cm) where 80 Kg/ha potassium was applied followed by K_3 (66.68cm) where 60 kg/ha potassium was applied. However, the lowest plant height was observed in K_0 treatment (61.76cm) where no potassium was applied. The results were quite similar with the findings of Abou El-Nasr and Ibrahim (2011). But, the observed plant height of this experiment is much higher than that of Subba *et al*. (2017) where they found maximum plant height of carrot was 36.00 cm. The differences in the results might be due the differences in experimental site and variety used for the experiment.

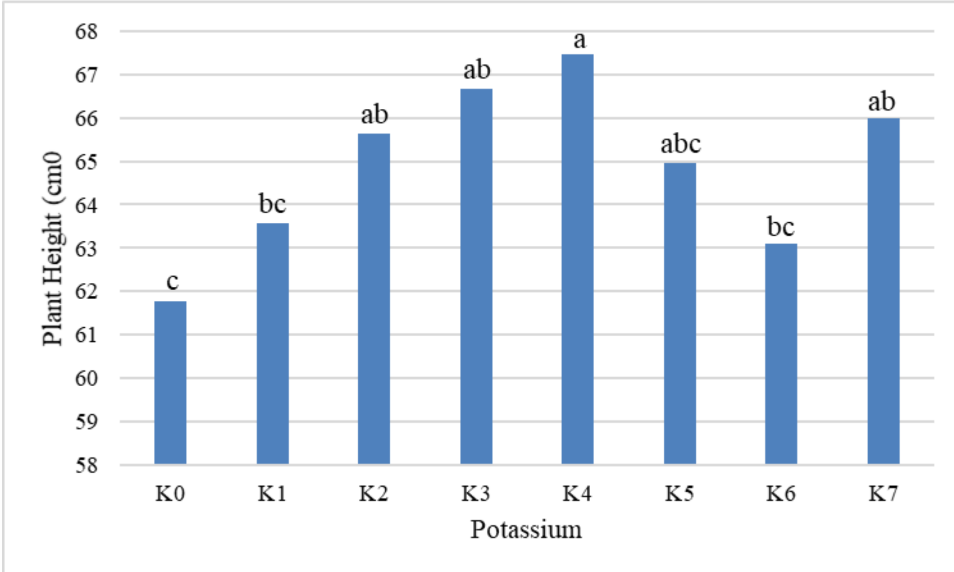


Figure 4.45 The effect of different doses of potassium on plant height of carrot. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Here,
K_0 = 0 kg K/ha, K_1 = 20 kg K/ha, K_2 = 40 kg K/ha,
K_3 = 60 kg K/ha, K_4 = 80 kg K/ha, K_5 = 100 kg K/ha,
K_6 = 120 kg K/ha, K_7 = 140 kg K/ha

4.3.1.2 Number of leaves per plant

The number of leaves per plant of carrot was significantly varied due to application of different doses of potassium (Figure 4.46). The highest number of leaves per plant was observed in K_4 treatment (8.6) where 80 kg/ha potassium was applied which was statistically similar with K_5 (8.26) where 100 Kg/ha potassium was applied. However, the lowest number of leaves per plant observed in K_0 treatment (6.26) where no potassium was applied.

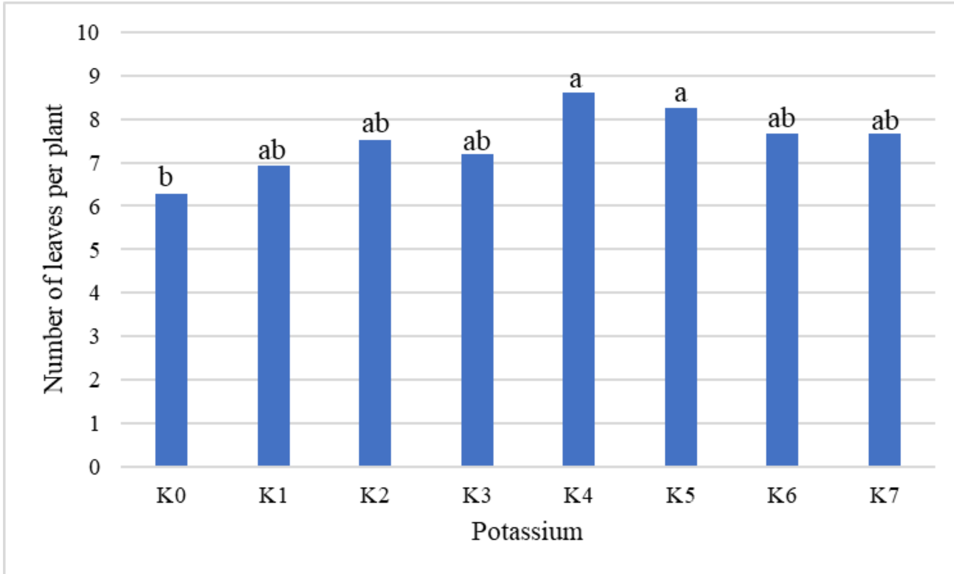


Figure 4.46 The effect of different doses of potassium on the number of leaves per plant of carrot. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Here,
K_0 = 0 kg K/ha, K_1 = 20 kg K/ha, K_2 = 40 kg K/ha,
K_3 = 60 kg K/ha, K_4 = 80 kg K/ha, K_5 = 100 kg K/ha,
K_6 = 120 kg K/ha, K_7 = 140 kg K/ha

4.3.1.3 Leaf length

The leaf length of carrot was significantly varied due to application of different doses of potassium (Figure 4.47). The maximum leaf length was observed in K_7 treatment (55.81cm) where 140 kg/ha potassium was applied which was statistically similar with K_5 (52.63cm) and K_3 (52.58cm) treatment (Table 4.17). However, the shortest leaf length was observed in K_0 treatment (48.13cm) where no potassium was applied. The results agree with those of Tohamy *et al*. (2011) who reported that the tallest carrot plants were obtained with high levels of K.

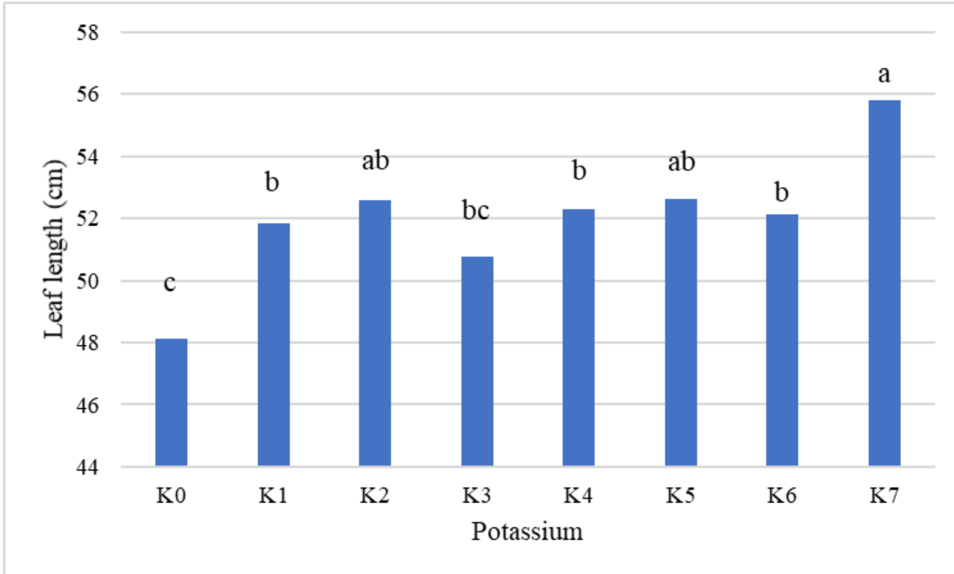


Figure 4.47 The effect of different doses of potassium on the leaf length of carrot. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Here,
K_0 = 0 kg K/ha, K_1 = 20 kg K/ha, K_2 = 40 kg K/ha,
K_3 = 60 kg K/ha, K_4 = 80 kg K/ha, K_5 = 100 kg K/ha,
K_6 = 120 kg K/ha, K_7 = 140 kg K/ha

Table 4.17 Effect of recommended fertilizers and manures on plant height, number of leaves/plant, leaf length, fresh weight/ plant yield/plot and yield of carrot

Treatment	Plant height (cm)	No. of leaves/plant	Leaf length (cm)	Fresh wt/plant	yield/plot	Yield (t ha^{-1})
K_0	61.76c	6.26b	48.13c	144.64e	19.28abc	29.52cd
K_1	63.56bc	6.93ab	51.85b	147.23de	19.63abc	30.05cd
K_2	65.647ab	7.53ab	52.58ab	156.83c	20.91abc	32.01abc
K_3	66.68ab	7.2ab	50.77bc	148.8d	19.84abc	28.84cd
K_4	67.467a	8.6a	52.31b	164.68b	21.95ab	33.61ab
K_5	64.95abc	8.266a	52.63ab	171.42a	22.85a	34.99a
K_6	63.11bc	7.66ab	52.12b	141.28f	18.83bc	30.37bcd
K_7	65.99ab	7.66ab	55.80a	131.87g	17.58c	26.92d
$LSD_{(0.05)}$	**1.12**	**0.80**	**0.98**	**6.91**	**2.43**	**2.23**
CV%	**8.32**	**2.312**	**8.78**	**11.45**	**9.87**	**3.56**

Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Here,
K_0 = 0 kg K/ha, K_1 = 20 kg K/ha, K_2 = 40 kg K/ha,
K_3 = 60 kg K/ha, K_4 = 80 kg K/ha, K_5 = 100 kg K/ha,
K_6 = 120 kg K/ha, K_7 = 140 kg K/ha

4.3.1.4 Fresh weight of leaves

Fresh weight of leaves per plant varied significantly with the application of different doses of potassium fertilizer (Figure 4.48). The maximum fresh weight of leaves was observed in K_7 treatment (76.33 g) where 140 kg/ha potassium was applied which was statistically dissimilar with other treatments. However, the lowest fresh weight of leaves K_2 (51.67g) which was statistically similar with K_0, K_1 and K_4. As plant height and number of leaves increased due to higher level of potassium fresh weight of leaves also increased with higher level of potassium.

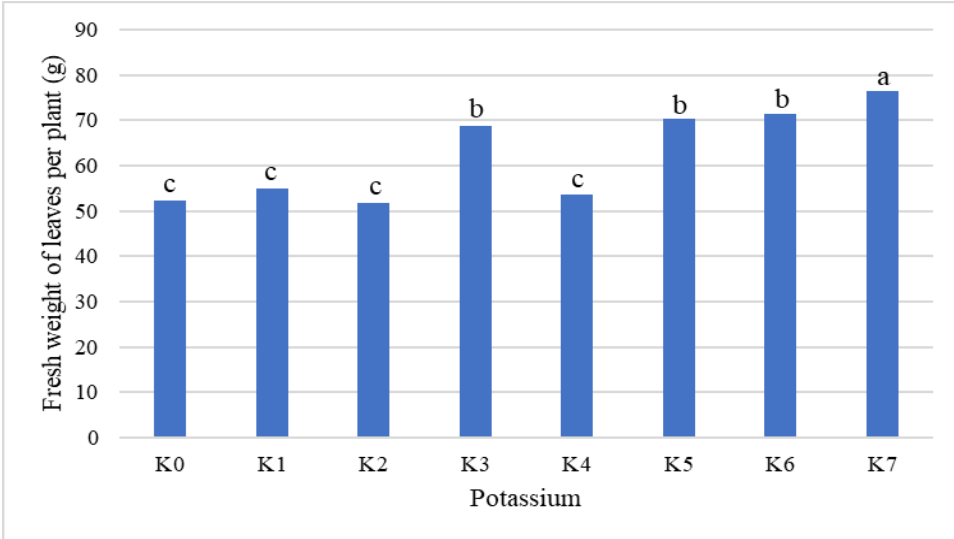


Figure 4.48 The effect of different doses of potassium on the fresh weight of leaves per plant of carrot. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Here,
K_0 = 0 kg K/ha, K_1 = 20 kg K/ha, K_2 = 40 kg K/ha,
K_3 = 60 kg K/ha, K_4 = 80 kg K/ha, K_5 = 100 kg K/ha,
K_6 = 120 kg K/ha, K_7 = 140 kg K/ha

4.3.2 Yield attributes and yield of carrot

4.3.2.1 Root length

The root length of carrot was significantly varied due to application of different doses of potassium (Figure 4.49). The maximum root length was observed in K_3 treatment (15.91 cm) where 60 Kg/ha potassium was applied which was statistically similar with K_5 (15.61 cm) and K_6 (15.32 cm). However, the shortest leaf length was observed in K_0 treatment (11.71 cm) where no potassium was applied. Hochmuth *et al.* (2006) reported that sufficient potassium was required for carrot production with good quality on sandy soils and high fertilization was necessary to compensate for potential losses of leached potassium.

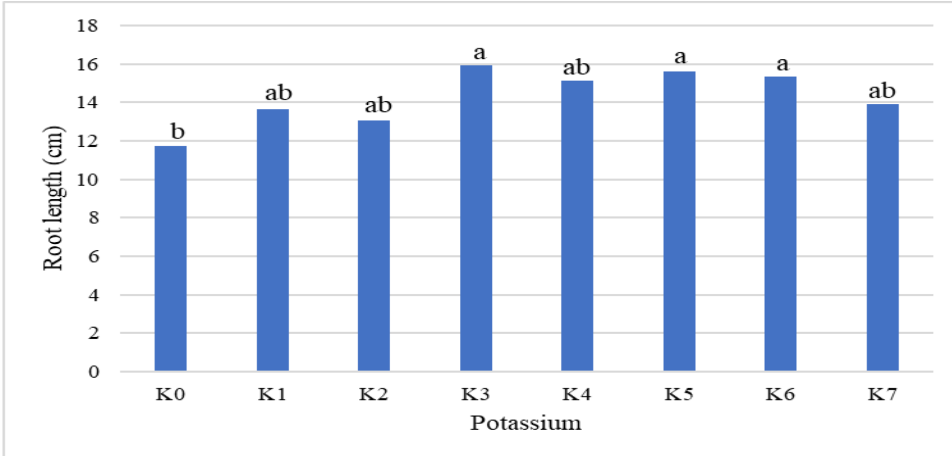


Figure 4.49 The effect of different doses of potassium on the root length of carrot. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Here,
K_0 = 0 kg K/ha, K_1 = 20 kg K/ha, K_2 = 40 kg K/ha,
K_3 = 60 kg K/ha, K_4 = 80 kg K/ha, K_5 = 100 kg K/ha,
K_6 = 120 kg K/ha, K_7 = 140 kg K/ha

4.3.2.2 Root diameter

The root diameter was not significantly influenced by the different doses of potassium (Figure 4.50). However, the highest root diameter was observed in treatment K_4 (2.1cm) and K_6 (2.1 cm) while the lowest root diameter was 2.03 cm found in K_5 and K_7. The results are similar with the findings of Subba *et al*. (2017) where they found root diameter of carrot ranged from 2.7 cm to 3.1 cm.

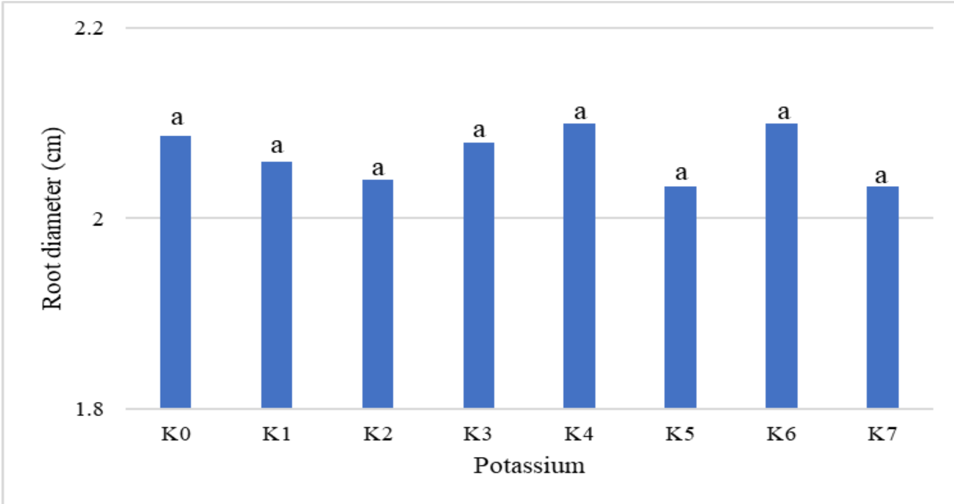


Figure 4.50 The effect of different doses of potassium on the root diameter of carrot. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Here,

K_0 = 0 kg K/ha, K_1 = 20 kg K/ha, K_2 = 40 kg K/ha,
K_3 = 60 kg K/ha, K_4 = 80 kg K/ha, K_5 = 100 kg K/ha,
K_6 = 120 kg K/ha, K_7 = 140 kg K/ha

4.3.2.3 Fresh weight of root

The fresh weight of root per plant of carrot was significantly varied due to application of different doses of potassium (Figure 4.51). The maximum fresh weight of root per plant was observed in K_5 treatment (171.42 g) where 100 Kg/ha potassium was applied which was statistically dissimilar with other treatments. However, the lowest fresh weight of roots per plant was observed in K_7 treatment (131.87 g) where 140 Kg/ha potassium was applied. Anjaiah and Padmaja (2006) reported that root yield and quality increased when levels of potassium and cow manure increased. But in our experiment a slight deviation was observed. It happened because the conclusion made by Anjaiah and Padmaja was based on an experiment where maximum dose of potassium was 100kg/ha. So, it might be concluded as that root yield and quality increased when levels of potassium increased upto a certain level, then it may show declining trend.

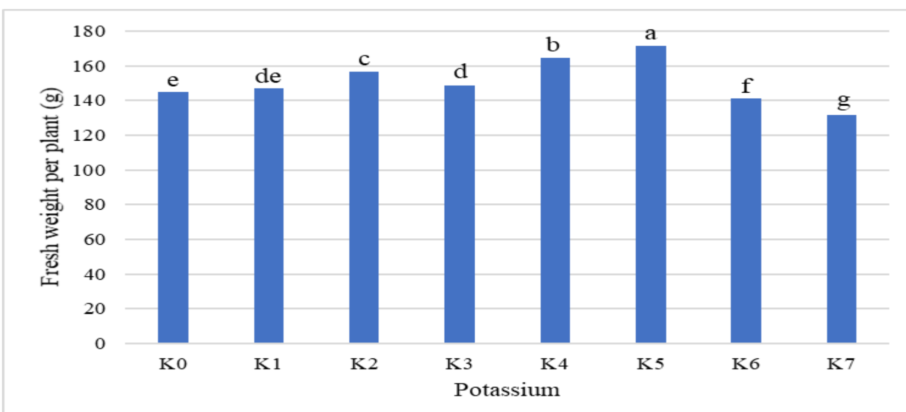


Figure 4.51 The effect of different doses of potassium on the fresh weight of root per plant of carrot. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Here,
K_0 = 0 kg K/ha, K_1 = 20 kg K/ha, K_2 = 40 kg K/ha,
K_3 = 60 kg K/ha, K_4 = 80 kg K/ha, K_5 = 100 kg K/ha,
K_6 = 120 kg K/ha, K_7 = 140 kg K/ha

4.3.2.4 Yield per plot

The yield per plot of carrot was significantly varied due to application of different doses of potassium (Figure 4.52). The maximum yield per plot was observed in K_5 treatment (22.86 kg) where 100 Kg/ha potassium was applied. However, the lowest yield per plot was observed in K_7 treatment (17.58) where 140 Kg/ha potassium was applied. Anjaiah and Padmaja (2006) reported that root yield and quality increased when levels of potassium and cow manure increased. But in our experiment a slight deviation was observed. It happened because the conclusion made by Anjaiah and Padmaja was based on an experiment where maximum dose of potassium was 100kg/ha. So, it might be concluded as that root yield and quality increased when levels of potassium increased up to a certain level, then root quality and yield may show declining trend.

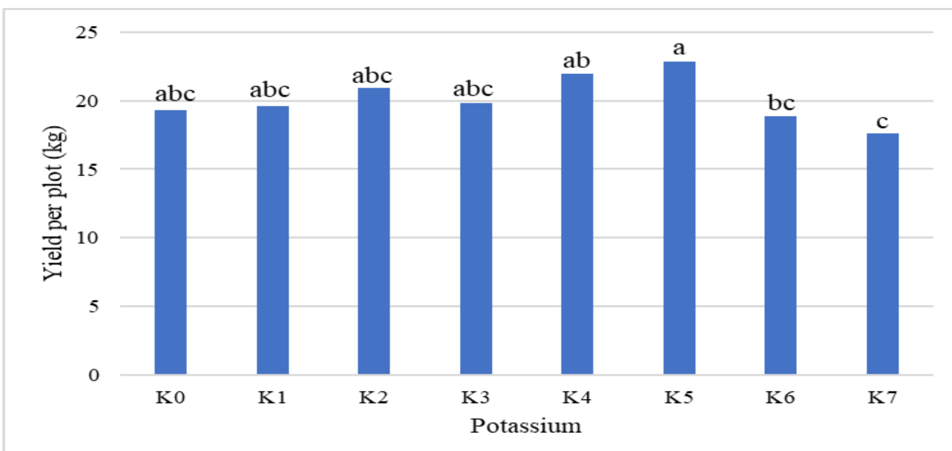


Figure 4.52 The effect of different doses of potassium on the yield per plot of carrot. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Here,
K_0 = 0 kg K/ha, K_1 = 20 kg K/ha, K_2 = 40 kg K/ha,
K_3 = 60 kg K/ha, K_4 = 80 kg K/ha, K_5 = 100 kg K/ha,
K_6 = 120 kg K/ha, K_7 = 140 kg K/ha

4.3.2.5 Total yield

The yield of carrot was significantly varied due to application of different doses of potassium (Figure 4.53). The maximum fresh weight of root per plot was observed in K_5 treatment (34.99 t/ha) where 100 Kg/ha potassium was applied. However, the lowest yield was observed in K_7 treatment (26.92) where 140 Kg/ha potassium was applied. Subba *et al.* (2017) found similar results in case of yield in their experiment.

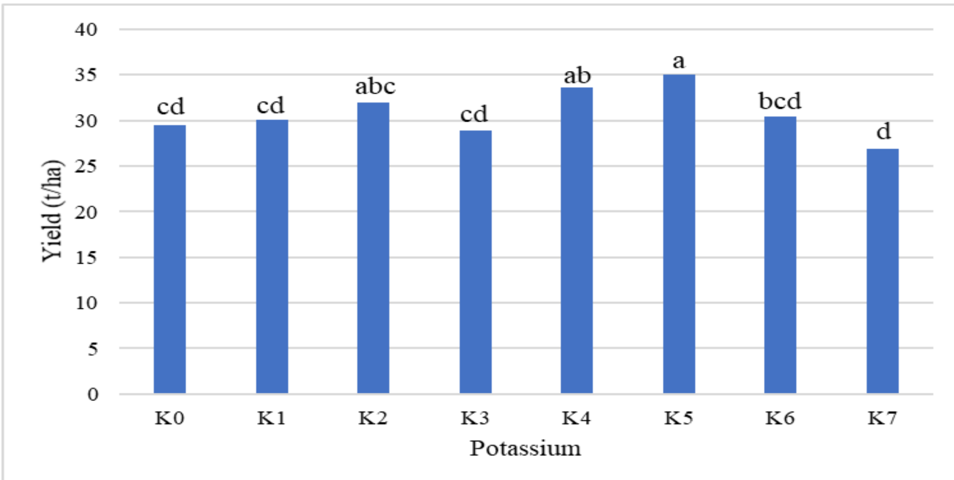


Figure 4.53 The effect of different doses of potassium on the total yield of carrot. Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Here,
K_0 = 0 kg K/ha, K_1 = 20 kg K/ha, K_2 = 40 kg K/ha,
K_3 = 60 kg K/ha, K_4 = 80 kg K/ha, K_5 = 100 kg K/ha,
K_6 = 120 kg K/ha, K_7 = 140 kg K/ha

Table 4.18 Effect of different doses of K fertilizers on fresh wt. of leaves, root diameter and root length of carrot

Treatment	Fresh wt. of leaves (g)	Root diameter (cm)	Root length (cm)
K_0	52.33c	2.08a	11.70b
K_1	55.00c	2.06a	13.62ab
K_2	51.66c	2.04a	13.06ab
K_3	68.66b	2.08a	15.90a
K_4	53.72c	2.1a	15.15ab
K_5	70.33b	2.03a	15.61a
K_6	71.33b	2.1a	15.32a
K_7	76.33a	2.03a	13.90ab
LSD (0.05)	**4.45**	**3.2**	**3.2**
CV%	**19.4**	**22.1**	**4.89**

Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Here,
K_0 = 0 kg K/ha, K_1 = 20 kg K/ha, K_2 = 40 kg K/ha,
K_3 = 60 kg K/ha, K_4 = 80 kg K/ha, K_5 = 100 kg K/ha,
K_6 = 120 kg K/ha, K_7 = 140 kg K/ha

4.3.3 Quality of root

4.3.3.1 Moisture reduction percentage

Quality of carrot root was measured in terms of moisture reduction percentage (Figure 4.54). The effect of K fertilizers on weight loss of carrot varied among the treatments (Table 4.19). Results showed that after seven days the lowest moisture reduction percentage was observed in K_5 (20.39%) while the highest moisture reduction percentage was found in K_0 (61.45%) followed by K_1 (60.24%). After 14 days, lowest moisture reduction percentage was observed in K_5 (37.87%) while the highest moisture reduction percentage was found in K_0 (76.93%)

followed by K_1 (75.30%). After 21 days, lowest moisture reduction percentage was observed in K_5 (54.07%) while the highest moisture reduction percentage was found in K_1 (77.10%) followed by K_0 (76.48%). So, it is quite evident that while considering short term storage (7 days) K_5 provided the best. Storage at room temperature up to 21 days showed linear weight loss at different rate of K fertilization. After 7 or so far as 21 days of storage at room temperature the loss of weight decreased gradually up to highest rate of K and maximum weight loss was occurred in control treatment. At higher rate from 60 kg K ha^{-1} up to 100 kg K ha^{-1}, the minimum weight loss of carrot were occurred, while control showed the maximum weight loss during room temperature.

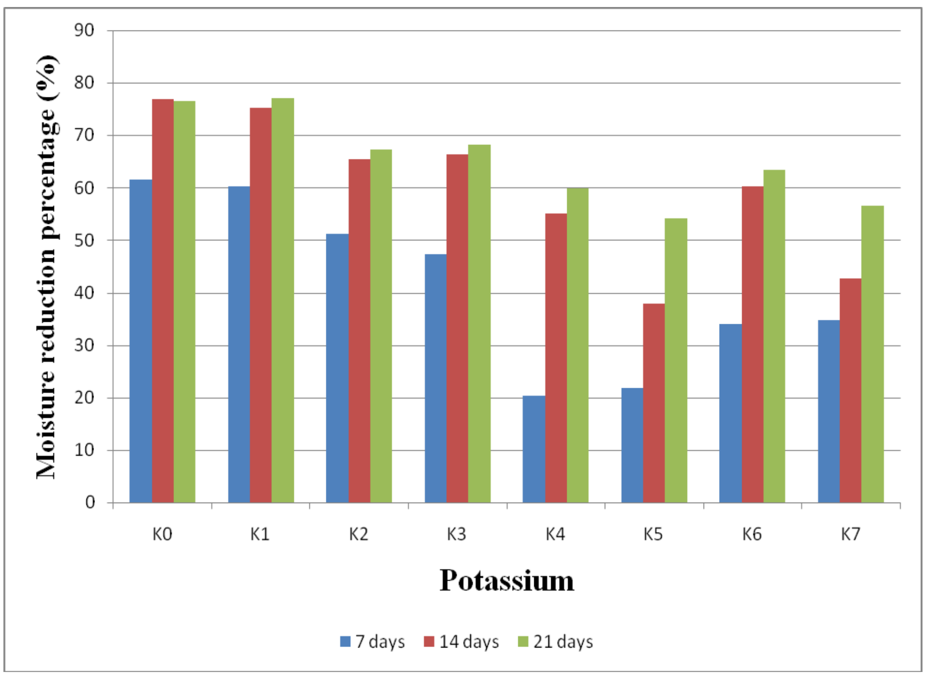


Figure 4.54 The effect of different doses of potassium on the moisture reduction percentage of carrot.

Here,
K_0 = 0 kg K/ha, K_1 = 20 kg K/ha, K_2 = 40 kg K/ha,
K_3 = 60 kg K/ha, K_4 = 80 kg K/ha, K_5 = 100 kg K/ha,
K_6 = 120 kg K/ha, K_7 = 140 kg K/ha

Table 4.19 : The effect of different doses of potassium on the moisture reduction percentage of carrot.

Treatment	7 days (%)	14 days (%)	21 days (%)
K_0	61.45a	76.93a	76.48a
K_1	60.24a	75.30a	77.10a
K_2	51.20b	65.40b	67.20b
K_3	47.27c	66.36b	68.18b
K_4	21.80e	55.00d	59.85d
K_5	20.39e	37.87f	54.07e
K_6	34.00d	60.16c	63.41bc
K_7	34.78d	42.60e	56.52de
LSD (0.05)	**4.5**	**13.65**	**18.22**
CV%	**22.32**	**11.34**	**8.76**

Here,
K_0 = 0 kg K/ha, K_1 = 20 kg K/ha, K_2 = 40 kg K/ha,
K_3 = 60 kg K/ha, K_4 = 80 kg K/ha, K_5 = 100 kg K/ha,
K_6 = 120 kg K/ha, K_7 = 140 kg K/ha

4.3.5 Soil chemical properties in post harvest soil of carrot field

4.3.5.1 Effect of recommended fertilizers along with manures on soil chemical properties in post harvest soil in carrot field

The application of different fertilizer and manure significantly influenced the pH, and N, P, K, S concentrations of post harvest soil.

Soil pH

The highest pH of post harvest soil (5.8) was recorded from K_6 treatment. There was no significant change in pH of post harvest soil of carrot field due to application of different fertilizers along with other manures where pH varied from 5.6 to 5.8 (Table 4.20) and compare to initial soil pH 5.6 (Table 3.2).

Soil organic carbon

There was no significant change in soil organic carbon (SOC) of post harvest soil of carrot field due to effect of manures and different fertilizers where SOC varied from 0.61 to 0.74 (Table 4.20) and compare to initial soil 0.61 (Table 3.2).

Soil Nutrient (NPKS)

Total N content in post harvest soil of carrot experimental field showed no significant variation due to the effect of manures and different fertilizers where N content varied from 0.055 to 0.080% (Table 4.20). The highest total N content 0.080% was found in the treatment of K_5 which was statistically similar with treatment K_3 and K_6. The lowest N content was observed in the treatment K_0.

Available P content in post harvest soil of carrot crop field showed significant variation due to application of manures and different fertilizers where P content varied from 20.65 to 26.58 ppm (Table 4.20). The highest P content 26.58 ppm was found in the treatment of K_7 which was statistically similar with treatment K_3 and K_5. The lowest P content in postharvest soil 20.65 ppm was found in treatment of K_0.

Exchangeable K content in postharvest soil showed insignificant variation due to effect of manures and different fertilizers where K content varied 0.162 to 0.173 meq 100^{-1}g (Table 4.20)

Available S content in post harvest soil of carrot crop field showed significant variation due to application of manures and different fertilizers where S content varied from 10.25 to 14.86 ppm (Table 4.20). The highest S content 14.86 ppm was found in the treatment of K_5 which was statistically similar with treatment K_3 and K_7. The lowest S content in postharvest soil 10.25 ppm was found in treatment of K_0.

Table 4.20. Effect of carrot with other recommended fertilizers on chemical properties of post harvest soil of carrot field

Treatments	pH	Organic carbon (%)	Total N (%)	Available P (ppm)	Exchangeable K (meq/100g)	Available S (ppm)
K_0	5.6	0.54e	0.055d	20.65e	0.17c	10.25cd
K_1	5.6	0.62bc	0.065c	22.87d	0.16ab	11.25bc
K_2	5.6	0.61bc	0.070bc	22.59ab	0.16a-c	11.85bc
K_3	5.6	0.73a	0.075ab	24.70cd	0.17ab	12.25b
K_4	5.6	0.64b	0.071b	22.25ab	0.16a	11.25bc
K_5	5.8	0.74a	0.080a	25.23a	0.17ab	14.86a
K_6	5.6	0.71ab	0.072b	23.35	0.16bc	11.95c
K_7	5.7	0.70ab	0.070bc	26.58	0.17a	12.58b
LSD (0.05)	**-**	**0.03**	**2.34**	**0.04**	**0.03**	**7.29**
CV%	**-**	**18.90**	**14.3**	**8.97**	**3.78**	**1.89**

Different letters indicate treatments are statistically dissimilar at 0.05 level of probability while similar letters indicate treatments are similar.

Here,

K_0 = 0 kg K/ha, K_1 = 20 kg K/ha, K_2 = 40 kg K/ha,
K_3 = 60 kg K/ha, K_4 = 80 kg K/ha, K_5 = 100 kg K/ha,
K_6 = 120 kg K/ha, K_7 = 140 kg K/ha

CHAPTER V

Summary and Conclusion

Three separate experiments were carried out during the period from October 2016 to April 2018. These were:

Experiment 1: Effect of potassium on the growth and yield of wheat under water stress condition

Experiment 2: Integrated nutrient management for boro rice to investigate potassium in soil.

Experiment 3: Improving quality and shelf life of carrots by applying potassium in soil.

The first experiment was conducted for wheat during October 2016 to March 2017 and second experiment was conducted for rice during December 2017 to April 2018 and third experiment was conducted for carrot during January 2018 to March 2018 at research field of Sher-e-Bangla Agricultural University, Dhaka.

5.1 Experiment 1: Effect of potassium on the growth and yield of wheat under water stress condition

BARI gom26 were used in this experiment for integrated nutrient management especially potassium balance in soil with control in RCBD with three replications where Factor A: Irrigation +recommended fertilizer with control had four levels (I_0= control (normal irrigations), I_1= Water stress at vegetative stage, I_2= Water stress at flower initiation stage, and I_3= Water stress at milking stage) and Factor B: Different doses of potassium had four levels also (K_0= 0 kg of K/ha, K_1= 60 kg of K/ha , K_2= 90 kg of K/ha, and K_3= 120 kg of K/ha).

The experiment was laid out in split plot design with three replications. Each block was sub divided into sixteen-unit plots. The treatments were randomly distributed to the unit plots in each block. The total number of plots was (16 X 3) 48. The unit plot size was 1.5 m to 3 m. Block to block distance was 0.75 m and plot to plot distance was 0.5 m. Data were collected on growth parameters, yield contributing parameters and yield parameters. Collected data were analyzed and adjusted by LSD test at 5% level of significance.

Water stress conditions influenced all the parameters. The tallest plant with (84.2 cm) height was found in control condition (I_0) where proper irrigation was applied in different growth stage. The shortest plant height (81.0 cm) was found in treatment (I_3). Highest number of tillers (5.20) in control condition had no significant difference with treatment I_1 where water stress or water stress was applied during their vegetative stage. But they were significantly different from other two treatments I_2 and I_3 where, water stress was applied to the plants in their flowering and milking stage. Results revealed that water stress during the flowering stage caused lowest number of tillers, which was (4.15). The highest number of effective tillers was found in Io that was (5.20) and lowest was recorded from I_2 treated plot (4.15). Highest number of non-effective tillers were (0.94) which was found in treatment I_2 having water stress in flowering initiation stage and it had no significant difference with the treatment I_3 where water stress was provided in milking stage. Lowest numbers of non-effective tillers were (0.61), which was found in treatment I_0 where proper irrigation was applied. Highest length of the flag leaf was (17.55 cm) which was observed in treatment I_0, where proper irrigation was applied to the plants. Lowest length of flag leaf was (15.51 cm) which was in treatment I_3.

Lowest ear length (15.32 cm) was found in treatment I_1 where water stress was applied in vegetative stage. Highest ear length (15.52 cm) was found in treatment I_2. The maximum number of spikelet per spike (57.9) was observed from treatment I_1, whereas the minimum number of spikelet per spike (53.8) was observed from I_0. Maximum number of fertile florets (61.4) were found from the treatments I_0 and I_2, both of them were statistically similar to each other. Minimum number of fertile florets (58.4) were found in the treatment I_3 where water stress was provided in the milking stage. The maximum number of filled grains per spike (43.0) was observed from I_0 which was statistically similar with I_2 (42.1) and I_3 (41.9), whereas the minimum number (39.8) was observed from I_1. The maximum number of unfilled grains per spike (4.7) was observed from I_1. The minimum number of unfilled grains per spike (3.25) was observed from I_0. The maximum number of total grains per spike (46.25) was observed from I_0 which was statistically similar (45.6 and 45.7) with I_2, I_3 and significantly different from I_1. While the minimum number of total grains per spike (44.4) was observed from I_1. The highest weight of 1000 grains (52.4 g) was observed from I_0 which was statistically similar with I_2 and I_1 (52.3 g and 52 g). While the lowest weight of 1000 grains (50.9 g) was observed from I_3.

The highest grain yield (3.60 t ha^{-1}) was observed from I_0 which was statistically similar (3.09 t ha^{-1}) with I_2, while the lowest grain yield (2.69 t ha^{-1}) was observed from I_3. The highest straw yield (2.8 t ha^{-1}) was observed from I_0 and the lowest straw yield (1.6 t ha^{-1}) was observed from I_3. The highest biological yield (5.80 t ha^{-1}) was observed from I_1, followed (5.40 and 4.99 t ha^{-1}) in I_0 and I_2, while the lowest biological yield (4.20 t ha^{-1}) was observed from I_3. The highest harvest index (60.10%) was observed from I_1 and I_2. whereas the lowest harvest index (51.46%) was found from I_0.

Application of potassium influence all the studied characters of wheat. Plant height was highest 84.20cm, in treatment K_3 where the dose of potassium was also highest and it is significantly different from all other treatments. Lowest plant height 81.00cm was recorded in control condition (K_0) where, no potassium was applied. Highest number of effective tillers (5.20) were found in treatment K_3 while the lowest number of effective tillers (4.00) were found in Control condition (K_0). Highest number of non-effective tillers were (1.08) which was observed in treatment K_0, where no potassium was applied to the plants. Lowest number of non-effective tillers were (0.62) which was in treatment K_1. Highest flag leaf length (17.25 cm) was found in treatment K_3 where (108 g) of potassium was applied. Shortest flag leaf length was (15.55 cm) which was noticed in treatment K_1.

From this study lowest ear length 15.18cm was found in treatment K_0. Highest ear length 15.52cm was found in treatment K_3. The maximum number of spikelet per spike (57.25) was observed from K_3 treatment while the minimum number of spikelet per spike (54.9) was observed in K_2. Maximum number of fertile florets (61.25) were found from the treatments K_3 and it was statistically similar with treatment K_1 and K_0 (Figure 4.16). Minimum number of fertile florets (58.9) were found in the treatment K_2 where 81gm potassium was provided. The maximum number of filled grains per spike (42.18) was observed from K_3 treatment, having significant difference with other treatments. While the minimum number of filled grains per spike (41.40) was found in K_1. The maximum number of unfilled grains per spike (4.7) was observed from K_2 treatment, while the minimum number of unfilled grains per spike (3.6) was found in K_3. The maximum number of total grains per spike (45.82) was observed from K_3 treatment, which was statistically similar (45.59) with K_0 followed by K_2

(45.42). While the minimum number of total grains per spike (45.25) was found in K_1. The highest weight of 1000 grains (52.75 g) was observed from K_2 treatment, which was statistically similar with K_3 and K_1 (52.5 and 51.6 g). The lowest weight of 1000 grains (50.7 g) was found in K_0.

The highest grain yield (3.14 t/ha) was observed from K_3 followed by (3.08 t/ha) in K_0 treatment, which were statistically different from all other treatment. The lowest grain yield (2.86 t/ha) was found in K_2. The highest straw yield (2.27 t/ha) was observed from K_3 treatment. Again, the lowest straw yield (2 t/ha) was found in K_2. The highest biological yield (5.41 t/ha) was observed from K_3 treatment, which was statistically similar (5.21 t/ha) with K_0. The lowest biological yield (4.88) was found in K_2. The highest harvest index (59%) was observed from K_2 treatment, which was statistically similar with K_0, while the lowest harvest index (58%) was found in K_3.

Combined effect of water stress conditions and different doses of potassium influenced the studied traits of wheat. The plant height ranged from lowest 78.73cm in the treatment combination I_3K_0 to the highest 84.69cm in the treatment combination of I_0K_3. Total number of tillers were lowest 3.87 in the treatment interaction of I_3K_1 which was statistically similar to the interaction I_2K_0. Highest number of tillers were 5.53 observed in the treatment interaction I_0K_3. Number of effective tillers ranged from 3.73 to 5.4, number of non-effective tillers were found lowest 0.33 in treatment interaction I_2K_3 which is statistically similar to I_2K_1 and I_1K_2, on the other hand highest non-effective tiller number was found in I_3K_0 (1.33). The length of flag leaf ranged from lowest 15cm in I_3K_2 interaction to the highest 19.29cm in I_0K_3 interaction.

The ear length ranged from lowest 14.81cm in the treatment combination I_1K_0 to the highest 16.55cm in the treatment combination of I_0K_3. Number of spikelet per spike were lowest 52.73 in the treatment interaction of I_2K_3 and Highest number spikelet per spike 59.47 observed in the treatment interaction I_3K_2. Number of fertile florets per spike ranged from 57 in I_3K_2 interaction to the highest number 64.87 in the interaction of I_0K_0. Number of filled grains per spike were found lowest 38.33 in treatment interaction I_0K_2 and highest filled grain number was found in I_1K_0 (44) which was statistically similar to I_1K_1. Number of unfilled grains per spike ranged from lowest 2.33 in I_1K_1 to the highest number 5 in I_0K_1 which was statistically similar to I_0K_2 interaction. The maximum number of total grains per spike (47.33) was observed from 1_3K_3, while the minimum number of total grains per spike (43.33) was recorded from I_0K_2. The highest weight of 1000 grains (54.67 g) was observed from I_1K_3, again the lowest weight of 1000 grains (49.67g) was recorded from I_3K_0.

The highest grain yield (4.04 t/ha) was observed from I_0K_3, while the lowest grain yield (2.29 t/ha) was recorded from I_0K_1. Interaction effect of different levels of irrigation and potassium fertilizer showed significant differences on straw yield. The highest straw yield (3.62 t/ha) was observed from I_0K_0, while the lowest straw yield (1.59 t/ha) was recorded from I_2K_0. The highest biological yield (7.80 t/ha) was observed from I_0K_3, while the lowest biological yield (4.28 t/ha) was recorded from I_3K_0 and I_3K_1. The highest harvest index (64.91%) was observed from I_2K_1, while the lowest harvest index (49.43%) was recorded from I_0K_3.

5.2 Experiment 2. Integrated nutrient management for boro rice to investigate potassium balance in soil

BRRI dhan28 were used in this experiment for integrated nutrient management especially potassium balance in soil.

Recommended fertilizer with control and different doses of potassium. BRRI dhan28 variety was used in this experiment and the experiment was laid out in an RCB design with three replications. Each block was sub divided into eleven-unit plots. The treatments were randomly distributed to the unit plots in each block. The total number of plots was (11 X 3) 33. The unit plot size was 2 m to 2 m. Block to block distance was 1 m and plot to plot distance was 0.5 m. Data were collected on growth, yield contributing and yield parameters and analyzed and adjusted by LSD test at 5% level of significance.

Different combinations of potassium treatments influenced the studied characters of boro rice. The tallest plant (100.0 cm) was produced in T_2 {Fertilizer recommended dose for BRRI dhan28 (100% MoP)}, which was statistically similar with the treatment T_3, T_5 and T_7 (96.5, 96.5 and 96.6 cm). The lowest plant height (88.1cm) was produced under control treatment, which was significantly different from others but statistically similar with T_4 & T_{11} treatments (90.5 & 90.6 cm).

The maximum total number of tiller hill^{-1} (26) was produced from T_9 {75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP} which was statistically similar with T_{10} and T_{11} (26). Minimum total number of tiller hill^{-1} (16.5) was produced form T_8 treatment. The maximum total number of tiller hill^{-1} (20.25) was produced from T_9 (75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP) which was statistically similar with all other treatments except T_8. Minimum total number of tiller hill^{-1}

(17) was observed form T_8 treatment and it was significantly different from all the other treatments. The maximum total number of non-effective tiller (6.1) was produced from T_{10} (75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP) which was statistically similar with all other treatments except T_8. Minimum total number non-effective tiller (1.2) was observed form T_8 treatment.

Longest (25.9 cm) panicle was produced from T_9 treatment (75% K supplement by cow dung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP), which was statistically similar with all other treatments except T_6. Lowest (22 cm) panicle length was produced form T_6 treatment (50% K supplement by cow dung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP) and it was significantly different from all the other treatments. Longest (29.9 cm) flag leaf was produced from T_{10} treatment (75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP), which was statistically similar with all other treatments except T_6. Lowest (25.2 cm) flag leaf length was produced form T_6 treatment (50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MoP) and it was significantly different from all the other treatments.

Results showed that highest number of filled grains panicle^{-1} was obtained (193.7) from T_8 treatment {50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP}, which was statistically similar with treatment T_2 and T_{10} (174 and 171.3) but significantly different from T_1 (164). The lowest number of filled grains panicle^{-1} (124.4) was found from T_6 and it was statistically similar with T_5, T_9 and T11 (132.7, 134 and 128) treatment. The highest number of unfilled grains panicle-1 was obtained (10.23) from T_6 treatment {50% K supplement by cowdung (2.50 t/ha) + 50% K (37.5 kg K/ha) from MOP}, followed by T_3 (8.5) which were statistically similar to each other. The lowest number of unfilled grains panicle^{-1} (6.04) was found from T_2 {Fertilizer recommended dose for BRRI dhan28 (100% MoP)} treatment. The highest number of total grains panicle^{-1} was obtained (200) from T_8 treatment {50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP}, followed by treatment T_2 and T_{10} (180.04 and 177.64) and they were statistically similar with each other but significantly different from T_8. The lowest number of filled grains panicle^{-1} (134.38) was found from T_{11} and it was statistically similar with T_6 (134.63) treatment.

The highest number of 1000 grains weight (0.2367 kg) was found in T_8 treatment {50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP}. On the other hand, lowest number of 1000 grains weight (0.2233 kg) was observed in the T_{10} treatment {75% K supplement by poultry liter (6.60 t/ha) + 25% K (18.75 kg K/ha) from MoP}.

The maximum grain yield (6.55 t ha^{-1}) was produced from T_8 treatment {50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP}, which was significantly different from the T_1 treatment (Control) producing minimum grain yield (2.35 t ha^{-1}). The maximum straw yield (7.76 t ha^{-1}) was produced from treatment T_6. The minimum straw yield (4.99 t ha^{-1}) was observed from T_1 (Control) treatment. The maximum biological yield (14.18 t ha^{-1}) was produced from T_8 treatment {50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP}. The minimum biological yield (7.34 t ha^{-1}) was observed from T_1 treatment. The maximum harvest index (47.09%) was produced from T_9 treatment {75% K supplement by cowdung (3.75 t/ha) + 25% K (18.75 kg K/ha) from MoP}. The minimum harvest index (32.02 %) was produce from T_1 treatment (control).

5.3 Experiment 3. Improving quality and shelf life of carrots by applying potassium in Soil.

The highest number of leaves per plant was observed in K_4 treatment (8.6) where 80 kg/ha potassium was applied which was statistically similar with K_5 (8.26) where 100 kg/ha potassium was applied. The lowest number of leaves per plant observed in K_0 treatment (6.26) where no potassium was applied. The maximum leaf length was observed in K_7 treatment (55.81 cm) where 140 kg/ha potassium was applied which was statistically similar with K_5 (52.63 cm) and K_3 (52.58 cm). The shortest leaf length was observed in K_0 treatment (48.13 cm) where no potassium was applied. The maximum fresh weight of leaves was observed in K_7 treatment (76.33 g) where 140 kg/ha potassium was applied which was statistically dissimilar with other treatments. The lowest fresh weight of leaves K_2 (51.67 g) which was statistically similar with K_0, K_1 and K_4.

The maximum root length was observed in K_3 treatment (15.91 cm) where 60 kg/ha potassium was applied which was statistically similar with K_5 (15.61 cm) and K6 (15.32 cm). However, the shortest leaf length was observed in K_0 treatment (11.71 cm) where no potassium was applied. , The highest root diameter was observed in treatment K_4 (2.1 cm) and K_6 (2.1 cm) while the lowest root diameter was (2.03 cm) found in K_5 and K_7. The maximum fresh weight of root per plant was observed in K_5 treatment (171.42 g) where 100 kg/ha potassium was applied which was statistically dissimilar with other treatments. The lowest fresh weight of roots per plant was observed in K_7 treatment (131.87 g) where 140 kg/ha potassium was applied. The maximum yield per plot was observed in K_5 treatment (22.86 kg) where 100 kg/ha potassium was applied. The lowest yield per plot was observed in K_7 treatment (17.58) where 140 kg/ha potassium was applied. The maximum fresh weight of root per plant was observed in K_5 treatment (34.99 t/ha) where 100 kg/ha potassium was applied. However, the lowest yield was observed in K_7 treatment (26.92) where 140 kg/ha potassium was applied.

Results showed that after seven days the lowest moisture reduction percentage was observed in K_5 (20.39%) while the highest moisture reduction percentage was found in K_0 (61.45%) followed by K_1 (60.24%). After 14 days, lowest moisture reduction percentage was observed in K_5 (37.87%) while the highest moisture reduction percentage was found in K_0 (76.93%) followed by K_1 (75.30%) (Table 4.19). After 21 days, lowest moisture reduction percentage was observed in K_5 (54.07%) while the highest moisture reduction percentage was found in K_1 (77.10%) followed by K_0 (76.48%). So, it is quite evident that while considering short term storage (7 days) K_5 provided the best. Storage at room temperature up to 21 days showed linear weight loss at different rate of K fertilization. After 7 or so far as 21 days of storage at room temperature the loss of weight decreased gradually up to highest rate of K and maximum weight loss was occurred in control treatment. At higher rate from 60 kg K ha^{-1} up to 100 kg K ha^{-1}, the minimum weight loss of carrot were occurred, while control showed the maximum weight loss during room temperature.

Conclusion

Experiment 1. Effect of potassium on the growth and yield of wheat under water stress condition

Normal irrigations tend to give better results in most of the cases. But as plants tries to produce more offspring while encountering stress I_3 (water stress at milking stage) that at milking stage produced highest grain yield and straw yield. Results also indicated that wheat plant most suffered when irrigation was omitted during vegetative and flowering stage. While considering impact of potassium it was evident that K_3 (120 kg K/ha) treatment produced the best results. While combing both water stress conditions and different doses of potassium I_0K_3 provided the best results.

Experiment 2. Integrated nutrient management for boro rice to investigate potassium balance in soil

It may be concluded that, the treatment combination of T_8 treatment (50% K supplement by vermicompost + 50% K from MoP) may be used for boro rice production. However, such type of study may be carried out in other agro-ecological zones of Bangladesh before final recommendation.

Experiment 3. Improving quality and shelf life of carrots by applying potassium in soil

It may be concluded that, application of potassium fertilizer with different dose had significant effect of carrot. Treatment T_5 which was 100kg potassium per hectare can be used for carrot production that can also enhanced root quality and shelf life of carrot. However, such type of study may be carried out in other agro-ecological zones of Bangladesh before final recommendation.

The above experimental findings, it can be concluded that K has a promising regulatory role in plant growth and development processes in different crops like wheat, rice and carrots. Maintaining the K level and water stress condition affected the yield of wheat. 50% K supplement by vermicompost (3.75 t/ha) + 50% K (37.5 kg K/ha) from MoP can be used for boro rice production. Storage of carrots at room temperature the loss of weight decreased gradually up to highest rate of K.

My research works strongly supported the notion that K is directly or indirectly responsible for higher yield of crops of wheat, rice and carrots.

CHAPTER VI

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APPENDICES

Appendix I: Mean square of plant height, flag leaf length, effective tillers per plant and non-effective tillers per plant of wheat

Source of Variation	Degrees of Freedom	Plant height	Flag leaf length	Effective tillars per plant	Non-effective tillars per plant
Replication	2	1.96	5.2	16.39	9.02
Irrigation	3	0.11*	35.44*	24.05**	4.96*
Replication*Irrigation	6	0.46**	76.83*	9.28*	3.21*
Treatment	3	0.60*	11.82*	1.5*	0.24*
Error	33	0.66	29.47	3.92	0.87
Total	47	-	-	-	-

Appendix II: Mean square of fertile florets per spike, filled grain, unfilled grain per spike, 1000 grain weight, grain yield of wheat

Source of Variation	Degrees of Freedom	Fertile florets per spike	Filled grain per spike	Unfilled grain per spike	1000 grain weight	Grain yield
Replication	2	5.2	16.39	9.02	4.52	1006.4
Irrigation	3	35.44*	24.05**	4.96*	5.46**	20060.9**
Replication*Irrigation	6	76.83*	9.28*	3.21*	6.96*	7935.00**
Treatment	3	11.82*	1.5*	0.24*	11.40*	2351.1**
Error	33	29.47	3.92	0.87	3.84	5137.7
Total	47	-	-	-	-	-

Appendix III: Mean square of plant height, total tillers, effective and non-effective tillers per

Source of Variation	Degree of freedom	Plant height	Total panicle per plant	Non-Effective panicle per plant	Effective panicle per plant	Leaf length
Replication	2	1.42	81.92	26.27	41.45	0.98
Treatment	10	34.74*	17.35*	5.49**	6.15*	4.94*
Error	20	21.03	20.14	6.91	17.5	7.24
Total	32	-	-	-	-	-

plant and flag leaf length of rice