

**EFFECT OF LEVELS AND SPLIT APPLICATION OF
POTASSIUM ON PRODUCTIVITY OF PADDY AND STATUS
OF POTASSIUM IN ALLUVIAL SOIL OF COASTAL REGION
OF KARNATAKA**

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**UNIVERSITY OF AGRICULTURAL AND HORTICULTURAL SCIENCES,
SHIVAMOGGA**

August, 2018

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Thesis submitted to the

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DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE, SHIVAMOGGA
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SHIVAMOGGA

CERTIFICATE

This is to certify that the thesis entitled “EFFECT OF LEVELS AND SPLIT APPLICATION OF POTASSSIUM ON PRODUCTIVITY OF PADDY AND STATUS OF POTASSIUM IN ALLUVIAL SOIL OF COASTAL REGION OF KARNATAKA” submitted in partial fulfillment of the requirements for the award of the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** to the College of Agriculture, Shivamogga, University of Agricultural and Horticultural Sciences, Shivamogga is a bonafide record of research work carried out by **Mr. YASHAWANTHKUMAR, S. M., ID. NO. MA1TAF0200** (yashawanthkumarsm@gmail.com) during the period of study in this university under my guidance and supervision and no part of this thesis has previously formed the basis for the award of any other degree, diploma, associateship, fellowship or any other similar titles

Shivamogga
August, 2018




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Effect Of Levels And Split Application Of Potassium On Productivity Of Paddy And Status Of Potassium In Alluvial Soil Of Coastal Region Of Karnataka

(YASHAWANTHKUMAR, S. M.)

ABSTRACT

A field experiment was conducted during *Kharif*, 2017 at Zonal Agricultural and Horticultural Research Station, Brahmavar, UAHS, Shivamogga to know the effect of levels and split application of potassium on productivity of paddy and status of potassium in alluvial soil of coastal region of karnataka. the experiment was laid out in randomised complete block design with ten treatments and replicated four times. Among different levels and split application of potassium, the treatment received potassium @ 75 kg K₂O ha⁻¹ with three equals split doses recorded higher plant height (115.05 cm), number of tillers per m² area (482.25), panicle length (23.05 cm), test weight (25.34 g), filled grains per panicle (108.98), grain and straw yield (7733 and 8815 kg ha⁻¹, respectively) and lowest growth and yield parameters was observed in treatment without application of potassium.


The higher uptake of potassium (168.79 kg ha⁻¹) was recorded in treatment, which received potassium level (75 kg K₂O ha⁻¹) in three equal splits compared to all other treatments.

An increase in the level of potassium application (45 to 75 kg ha⁻¹) either as basal or in splits, increased the water soluble and non-exchangeable potassium in soil after harvest of crop and lattice potassium decreased with increase in level of potassium application.

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ಕರ್ನಾಟಕ ಕರಾವಳಿ ಪ್ರದೇಶದ ಮೆಕ್ಕಲು ಮಣ್ಣಿನಲ್ಲಿನ ಪೊಟ್ಯಾಷಿಯಂನ ಸ್ಥಿತಿ, ಅದರ ಪ್ರಮಾಣ ಮತ್ತು ಪ್ರಮಾಣಗಳ ವಿಭಜನೆಯಿಂದ ಭತ್ತದ ಉತ್ಪಾದನೆಯ ಮೇಲಾಗುವ ಪರಿಣಾಮದ ಅಧ್ಯಯನ


(ಯಶವಂತಕುಮಾರ, ಎಸ್. ಎಂ.)

ಸಾರಾಂಶ

ಕರ್ನಾಟಕ ಕರಾವಳಿ ಪ್ರದೇಶದ ಮೆಕ್ಕಲು ಮಣ್ಣಿನಲ್ಲಿನ ಪೊಟ್ಯಾಷಿಯಂನ ಸ್ಥಿತಿ, ಅದರ ಪ್ರಮಾಣ ಮತ್ತು ಪ್ರಮಾಣಗಳ ವಿಭಜನೆಯಿಂದ ಭತ್ತದ ಉತ್ಪಾದನೆಯ ಮೇಲಾಗುವ ಪರಿಣಾಮವನ್ನು ತಿಳಿದುಕೊಳ್ಳಲು ೨೦೧೭ರ ಮುಂಗಾರಿನಲ್ಲಿ ವಲಯ ಕೃಷಿ ಮತ್ತು ತೋಟಗಾರಿಕಾ ಸಂಶೋಧನಾ ಕೇಂದ್ರ, ಬ್ರಹ್ಮಾವರದಲ್ಲಿ ಕ್ಷೇತ್ರ ಪ್ರಯೋಗವನ್ನು ನಡೆಸಲಾಯಿತು. ಈ ಪ್ರಯೋಗವು ಓಟ್ಟು ೧೦ ಉಪಚಾರಗಳನ್ನು ಒಳಗೊಂಡಿದ್ದು, ೪ ಪುನರಾವತನೆಗಳಲ್ಲಿ ಯಾದೃಚ್ಛಿತ ಸಂಪೂರ್ಣ ತಾಕು ವಿನ್ಯಾಸ ಪದ್ಧತಿಯಲ್ಲಿ ಅಳವಡಿಸಲ್ಪಟ್ಟಿತ್ತು. ವಿವಿಧ ಪ್ರಮಾಣ ಮತ್ತು ಹಂತದ ಪೊಟ್ಯಾಷಿಯಂ ಅನ್ವಯಗಳಲ್ಲಿ, ೭೫ ಕಿ.ಗ್ರಾಂ. ಪೊಟ್ಯಾಷಿಯಂ ಪ್ರತಿ ಹೆಕ್ಟೇರಿಗೆ ಮೂರು ಹಂತದ ವಿಭಜಿತ ಪ್ರಮಾಣ ಹಾಕಿದ ತಾಕಿನಲ್ಲಿ ಹೆಚ್ಚಿನ ಸಸ್ಯಗಳ ಎತ್ತರವನ್ನು (೧೧೫.೦೫ ಸೆ.ಮೀ.) ದಾಖಲಿಸಿದೆ, ಪ್ರತಿ ಮೀಟರ್‌ಗೆ ಹೆಚ್ಚಿನ ತೆಂಡೆಯು (೪೮೨.೨೫), ತುಂಬಿದ ಕಾಳುಗಳು (೧೦೮.೯೮), ಧಾನ್ಯ ಮತ್ತು ಹುಲ್ಲಿನ ಇಳುವರಿ (ಕ್ರಮವಾಗಿ ೭೭೩೩ ಮತ್ತು ೮೮೧೮ ಕಿ.ಗ್ರಾಂ. ಪ್ರತಿ ಹೆಕ್ಟೇರಿಗೆ) ದಾಖಲಾಗಿದೆ. ಇದಲ್ಲದೆ ಪೊಟ್ಯಾಷಿಯಂ ಹಾಕದೆ ಇರುವ ತಾಕಿನಲ್ಲಿ ಕಡಿಮೆ ಬೆಳವಣಿಗೆ, ಮತ್ತು ಇಳುವರಿ, ದಾಖಲಾಗಿದೆ.

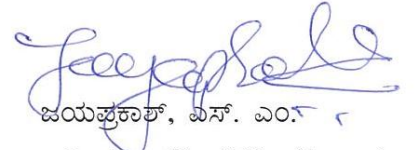
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LIST OF TABLES

Table No.	Title	Page No.
1	Soil physico-chemical properties of the experimental site	25
2	Effect of potassium levels and its split application on growth and yield parameters of paddy	34
3	Effect of potassium levels and its split application on grain, straw yield and harvest index of paddy.	36
4	Effect of potassium levels and its split application on nutrient content of paddy at 30 DAT, 60 DAT and at harvest.	38
5	Effect of potassium levels and its split application on nutrient content (%) in straw and grain of paddy after the harvest.	40
6	Effect of potassium levels and its split application on nutrient uptake (kg ha^{-1}) by paddy.	42
7	Effect of potassium levels and its split application on pH, EC (dS m^{-1}) and organic carbon (g kg^{-1}) in soil after the harvest of paddy.	43
8	Effect of potassium levels and its split application on primary and secondary nutrients in soil after the harvest of paddy.	44
9	Effect of potassium levels and its split application on potassium forms (mg kg^{-1}) after the harvest of paddy.	47
10	Effect of levels and split application of potassium on potassium use efficiency (%) in paddy.	49
11	Correlation among potassium forms with yield parameter, K content in grain and straw.	50

LIST OF FIGURES

Figure No.	Title	Between Page
1	Monthly metrological data for the experimental period <i>Kharif</i> 2017, Brahmavar	25 - 26
2	Plan of layout the of experimental plot	25 - 26
3	Effect of potassium levels and its split application on plant height (cm) and number of tillers per m ² .	52 - 53
4	Effect of potassium levels and its split application on filled grains, chaffy grains per panicle and test weight (g) of paddy grains.	52 - 53
5	Effect of potassium levels and its split application on grain and straw yield (kg ha ⁻¹) of paddy.	52 - 53
6	Effect of potassium levels and its split application on K content (%) at 30 DAT, 60 DAT and at harvest.	54 - 55
7	Effect of potassium levels and its split application on potassium uptake (kg ha ⁻¹) by paddy grain and straw.	54 - 55
8a	Forms and distribution of potassium (mg kg ⁻¹) in soil after harvest of paddy in treatment receiving 45 kg potassium as basal dose.	54 - 55
8b	Forms and distribution of potassium (mg kg ⁻¹) in soil after harvest of paddy in treatment receiving 60 kg potassium as basal dose.	54 - 55
8c	Forms and distribution of potassium (mg kg ⁻¹) in soil after harvest of paddy in treatment receiving 75 kg potassium as basal dose.	54 - 55
8d	Forms and distribution of potassium (mg kg ⁻¹) in soil after harvest of paddy in treatment receiving 45 kg potassium in two equal splits.	54 - 55
8e	Forms and distribution of potassium (mg kg ⁻¹) in soil after harvest of paddy in treatment receiving 60 kg potassium in two equal splits.	54 - 55
8f	Forms and distribution of potassium (mg kg ⁻¹) in soil after harvest of paddy in treatment receiving 75 kg potassium in two equal splits.	54 - 55
8g	Forms and distribution of potassium (mg kg ⁻¹) in soil after harvest of paddy in treatment receiving 45 kg potassium in three equal splits.	54 - 55
8h	Forms and distribution of potassium (mg kg ⁻¹) in soil after harvest of paddy in treatment receiving 60 kg potassium in three equal splits.	54 - 55
8i	Forms and distribution of potassium (mg kg ⁻¹) in soil after harvest of paddy in treatment receiving 75 kg potassium in three equal splits.	54 - 55
8j	Forms and distribution of potassium (mg kg ⁻¹) in soil after harvest of paddy in treatment receiving no potassium.	54 - 55

LIST OF PLATES

Plate No.	Title	Between Page.
1	General view of experimental plot	29 - 30
2a	Comparison of treatments at the time of harvest	38 – 39
2b	Comparison of treatments at the time of harvest	38 – 39
2c	Comparison of treatments at the time of harvest	38 – 39

LIST OF SYMBOLS AND ABBREVIATIONS

% : per cent	P: Phosphorus
& : and	K: Potassium
@ : at the rate of	Ca: Calcium
-1 : per	Mg: Magnesium
cm : centimetre	Fe: Iron
cm ⁻¹ : per centimetre	Al: Aluminium
DAS: Days after sowing	p ^H : negative logarithm of hydrogen ion activity
DMP: Dry matter production	plant ⁻¹ : per plant
dS m ⁻¹ : deci siemens per meter	q ha ⁻¹ : quintal per hectare
<i>et al.</i> : and others	SEm ±: Standard error of mean
Fig.: Figure	t ha ⁻¹ : tonnes per hectare
g : grams	<i>viz.</i> ,: namely
ha: hectare	
ha ⁻¹ : per hectare	
HI: Harvest index	
i.e.: Which is to say; in other words	
K ₂ O: Potash	
kg ha ⁻¹ : kilogram per hectare	
LAI: Leaf area index	
m: metre	
mm: millimetre	
N: Nitrogen	
NS: Non significant	
°C: Degree centigrade	

Introduction

I INTRODUCTION

Rice is the world's second most important cereal crop. Nearly 482 million metric tons of rice were produced in the last year worldwide. Asia has the largest share in world rice production. China is the world's leading rice producer, followed by India. Worldwide rice is grown in an area of 158.8 m ha with a production of 740.9 mt out of which 90 per cent of rice is grown and consumed in Asian countries (Anon, 2016).

India occupies a prime position in rice production among the food crops cultivated in the world. India has the largest area (43.95 million hectares) among rice growing countries and stands second in production (106.54 million tonnes) with the productivity of 2,372 kg/ha. The demand for rice is growing every year and it is estimated to be 180 million tonnes of raw rice (120 mt milled rice) need to be produced in India by 2020. This means the productivity needs to be doubled from the current level (Mishra *et al.*, 2006) under the declining land and water resource status. The major rice-growing states in the country are West Bengal, Andhra Pradesh, Chhattisgarh, Tamil Nadu, Karnataka, Assam, Maharashtra, Orissa, Punjab and Gujarat. In Karnataka, rice is grown in an area of 12.78 lakh hectares with an annual production of 33.64 lakh tonnes (Anon, 2015). The coastal region contributes over 20 per cent of total paddy area of the country.

Rice is the predominant crop in coastal region which is their staple food. This accounts for over 20 per cent of the total rice area of the country. The coastal region represents nearly all rice ecosystems namely; irrigated, rainfed, shallow land, rainfed semi deep, deep water and upland. The productivity of rice in coastal Karnataka is low due to heavy rainfall, low potassium status, leaching of basic cations such as Ca, Mg, K *etc.*, inadequate and improper time and method of application of nutrients, which leads to poor fertility status of the soil.

Potassium is an essential nutrient for all living organisms including plants and animals and its importance in Indian agriculture has increased the intensification of agriculture. It is a univalent cation found in largest concentration (100 - 200 mM) in the plant cell sap and hence it is called a "master cation." Potassium is ionic (K^+) and mobile in plants.

Among the plant nutrients, potassium is considered to be the 2nd important essential plant nutrient element for crop production. It plays a major role in crop growth and development and can alleviate the sterility problem in rice. It is often described as the "Quality Element" for crop production (Kaliha *et al.*, 1995). Potassium (K) is considered next to nitrogen (N) as regards its role in rice production and rice usually takes up more K than N. Potassium plays vital role in

enzyme activation, water regulation (osmotic regulations), energy relations, translocations of assimilates, photosynthesis, protein and starch synthesis (Naidu *et al.*, 2011). Over sixty enzymes require K for their activation. Due to K deficiency, older leaves may show spots or marginal burn starting from tips, susceptibility to diseases, drought and cold injury. Poor pollen viability causes a large percentage of sterile or unfilled spikelets and this retards carbohydrate translocation due to potassium deficiency (Mathad *et al.*, 2002). Potassium helps to control or reduces the severity of plant diseases and increases the plant's resistance to drought and other stresses. It performs many functions in the plant, such as promoting growth and increasing yield, increasing resistance to pests, promoting root growth, regulating water utilization by the plant, strengthening plant tissues and preventing lodging. Lodging of rice plant causes sterility during flowering, which causes the yield reduction in rice. Potassium increases the strength of rice stalk and thus prevents lodging and sterility.

Weather and climate significantly affect agricultural productivity in any area. Agricultural production of any region is being regulated by the prevailing climate of the area through temperature, rainfall, radiation, sunshine duration, light intensity *etc.*, (Sastri, 2010). Temperature and humidity are importance factors for enhancing the nutrient availability and their role in disease and pest infestation is well documented. The relationship between two or more weather parameters with grain in yield of crops can be used for yield prediction well before the actual harvesting of crops (Sastri *et al.*, 1996).

Soil potassium exists in four different forms *viz.*, water soluble potassium, exchangeable potassium, non-exchangeable potassium and mineral potassium. Major portion of soil potassium exists as constituent of mineral structure and in fixed or non-exchangeable forms with a minor portion as water-soluble K and exchangeable potassium.

The different forms and availability of potassium are most important while studying the response to potassium application because potassium supply to crop plants is a complex phenomenon involving relationships among the various potassium fractions in the soil. Plants not only utilize the readily available potassium but also the non-exchangeable potassium and mineral potassium during the crop growth.

Solution potassium and exchangeable potassium are replenished by non-exchangeable potassium when the former are depleted by plant removal or by leaching. Some non-exchangeable potassium held in the inter layers of expandable 2:1 type of clay minerals such as illite and vermiculite can be released relatively easy to provide a substantial portion of the potassium removed by crops during the

growing season. A potassium soil test should measure a proportional amount of non-exchangeable potassium that can become available during the growing season, or it must show the relationship between readily available forms and potential release of non-exchangeable potassium over a wide range of soil (Wang *et al.*, 2011).

The recommended dose of potassium is being applied at the time of transplanting and at panicle initiation stage of paddy in the coastal zone. But, leaching loss of K due to high rainfall, low K content and acidic nature of these soils are the reasons for low availability of K in soils which ultimately reduce the yield of crops (Yadav *et al.* 2004). Therefore, split application of potassium helps to prevent losses by leaching and fixation by soils and increases the grain yield (Devendra *et al.*, 1999).

In the view of the above facts, the information on the distribution of potassium fractions in paddy grown soils of the coastal area to know more about the different levels and split application of potassium on paddy in the coastal soil of Karnataka, a study entitled “Effect of levels and split application of potassium on the productivity of paddy and status of potassium in alluvial soil of coastal region of Karnataka” was carried out with the following objectives:

1. To study the effect of levels and split application of potassium on yield and uptake of potassium by paddy
2. To study the effect of levels and split application of potassium on the available status of potassium in the soil and
3. To study the effect of levels and split application of potassium on the distribution of potassium fractions in soil

Review of Literature

II REVIEW OF LITERATURE

Potassium is often absorbed by plants in amounts equal to or greater than nitrogen, which has drawn the attention of several research scientists to understand its behavior in different soils and study the crop response to applied potash fertilizers. Among the nutrients, potassium is absorbed in greater quantities by rice, especially by high yielding cultivars and it plays a significant role in improving sterility of rice. A thorough understanding of potassium status in the soil could be possible only by measurement of several parameters that are related to its different forms in the soil solution and the solid phase of soil. Therefore, to understand the dynamics of potassium in soils which involves forms and distribution of potassium, fixation and release characteristics, availability and uptake by crops are very much essential for efficient management of K for sustainable crop production. Keeping these things in view, literatures related to the present investigation have been viewed and some of them are presented below.

2.1 Effect of potassium application on the uptake of K by rice

2.2 Available potassium status

2.3 Forms and distribution of potassium in soils

2.4 Dynamic equilibrium among different forms of soil potassium

2.1 Effect of K application on the uptake of K by rice

Devendra *et al.* (1999) conducted a field experiment to assess the K uptake of rice in Agra district, India. They found that rice crop responded significantly to potassium application up to 90 kg K₂O ha⁻¹. Further, they observed that the content and potassium uptake by rice grain and straw increased significantly with successive increase in potassium levels.

Vijaynarayan *et al.* (1992) indicated that grain yield increased up to the application of 60 kg K₂O ha⁻¹ in the case of IET3280 and CO29. Similarly, it was found that yield increase up to application 80 kg K₂O ha⁻¹ in the case of Kannki when 0, 40, 60, and 80 kg K₂O ha⁻¹ were given. Pandey *et al.* (1993) found that increasing rate of K₂O application increased plant K concentration and uptake.

Thakur *et al.* (1993) performed a field experiment at Rajendra Agricultural University Farm, Pusa (Bihar) to find out the effect of the application of potash on wetland rice. The result indicated that with an increase in the potassium level up to 66 kg K ha⁻¹ there was an increase in number of total tillers m⁻².

Dhull and Kashyap (1994) conducted a field trial during 1984-86 on medium to high available potassium soil in Sirsa district of Haryana, India. They found that average yield of rice cv. PR 106 was 5.49, 6.33, 6.76 and 6.84 t ha⁻¹ with 0, 30, 60 and 90 kg K₂O ha⁻¹, respectively.

Kaliha *et al.* (1995) experimented with rice cv. IR20 and observed that grain yield increased significantly with increasing levels of K up to 40 kg K₂O ha⁻¹, which was mainly due to an increase in number of panicle m⁻² and number of filled grains panicle⁻¹.

Sarker *et al.* (1995) carried out a field experiment at the experimental farm of Calcutta University on Gangetic Alluvial soils during the *Kharif* seasons of 1991 and 1992, and found that application of 100 kg N + 75 kg K₂O ha⁻¹ in three equal splits at transplanting, active tillering and panicle initiation stage proved most effective in increasing yield attributes and grain yield of high yielding rice.

Roy *et al.* (1995) showed that grain yield and K uptake increased with the rate of 0-51 kg K ha⁻¹ application. They also stated that water soluble, exchangeable and reserve K in soil was positively correlated with yield and K uptakes of crops.

Ammal and Muthiah (1995) reported the effect of organic manure (raw and composted coir pith) and graded levels of potassium application on forms of soil K at different growth stages of rice in a greenhouse experiment. A significant variation of available K, water-soluble K, exchangeable K and non-exchangeable K was observed due to manure and potassium addition. All the forms of potassium were increased at tillering stage but decreased at harvest stage.

Mahanta and Choudhury (1997) showed that rice was given 0 to 60 kg N + 0 to 80 kg K₂O ha⁻¹ and grain yield peaked at 40 kg N and 60 kg K₂O ha⁻¹. Application of 40 or 60 kg N ha⁻¹ and 60 kg K₂O ha⁻¹ increased the concentration of Ca and Mg in plants at the flowering stage and in grain and straw at harvest.

Pillai and Anasuya (1997) experimented in the greenhouse where rice cv. MTU 5249 was given the equivalent of 0-150 kg K₂O ha⁻¹. Grain and straw yield increased with increasing K rates up to 75 kg ha⁻¹, above which increases were negligible. Maintenance of K concentration in the top three leaves at a level higher than 2.76 per cent at the maximum tillering stage was essential for achieving maximum grain yield.

Sharma and Baruah (1997) conducted a field experiment at Assam, India with rice cv. Krishna. The rice was given 25, 50, 75 or 100 kg K ha⁻¹ as basal 2 and 3 splits. Split application of K increased grain yield compared with a single basal

dose. They also obtained the highest yield with 75 kg K ha⁻¹ applied in 3 equal splits.

Thakur and Patel (1998) conducted a field experiment to study the effect of the split application of potassium with FYM on rice under rain fed conditions. Application of potassium influenced the dry matter production, leaf area index, leaf area duration, crop growth rate, net assimilation rate and relative growth rate, which were ultimately reflected in higher grain yields of rice.

Singh *et al.* (1999) reported that application of potassium also enhanced the grain and straw production. However, the effect was limited to the application of 30 kg K₂O in both grain and straw. The content and uptake of K and N in plants increased significantly with their application.

Anon (2011) evaluated the performance of Bina dhan-4 aman rice variety comparing to other locally grown rice varieties. Potassium treatment with 80 kg potassium ha⁻¹ produced the maximum grain yield of 4.97 t ha⁻¹.

Kanti *et al.* (2000) reported that application of 50 kg K₂O in two equal splits (1/2 at tillering), produced significantly higher grain and straw yields of rice and also had higher uptake and recovery to applied K by rice over its basal application.

Pal *et al.* (2000) observed that the split application of potassium resulted in higher grain yield over the basal dose at the same dose of 60 kg K₂O ha⁻¹. However, there was a distinct variation among three split treatment of K as well as between the two varieties tested.

Sengar *et al.* (2000) observed that the K uptake by rice grain was increased with the combined application of manure and fertilizer.

Singh and Singh (2000) conducted a field experiment to evaluate the effect of levels and phases of K application on rice and wheat crops during *Kharif* 1989 to *Kharif* 1991. K application significantly enhanced the growth and yield of both crops over no K application. Rice plant height and a number of shoots were not significantly affected in 1989 while in 1990 and 1991; plant height increased up to application of 60 kg and 90 kg K₂O ha⁻¹, respectively and number of shoots up to 90 kg K₂O ha⁻¹ in 1989, 1990 1991, respectively. Higher grain and straw yield of rice was obtained at 90 kg K₂O ha⁻¹ in all the years.

Kundu *et al.* (2001) conducted a greenhouse experiment to examine the comparative solubility, plant uptake and availability of iron (Fe) and (K) to rice in two soils a near neutral Tropudalf (Maahas clay loam) and a strongly acidic sulfaquept (Burabod soil) under three soil water regimes (moist, wet and flooded conditions). While flooding increased water-soluble K in the Mahas soil,

concentration and total uptake of K by 8 week old shoots in Burabod soil were lowest under flooded and highest under the moist regime. Although the availability of K in the acidic-sulphate soil was similar under all three water regimes, plant K uptake was markedly lower under the flooded condition. Data on Fe availability in the soils and its uptake by plants indicated that excessive Fe depressed K uptake by rice.

Mitra *et al.* (2001) conducted an experiment in the alluvial soils (*Inceptisol*) of Orissa India, at two locations (Village Siula in Pun district and Village Uttara in Khurda district) for three consecutive years in a rice-groundnut sequence. There were four levels of K₂O (0, 30, 60, 90 kg ha⁻¹) for rice and three levels of K₂O (72, 60, 80 kg ha⁻¹ for groundnut). The results showed a significant increase in yield of both rice and peanut with increased levels of K. Averaged over cropping cycles, application of 60 kg K₂O was found to be optimum for *Kharif* rice. The N, P, K and S uptakes of rice increased significantly with levels of K.

Sahu (2001) pointed out that both grain and straw yields increased with the addition of K. The application of 123 kg K ha⁻¹ increased average grain yield by 136 per cent in Jaya, 71 per cent in Pathara, 59 per cent in Mahsuri, and 42 per cent in Parijat. The effect of K application on straw yield was similar to that of grain yield. He also reported that the application of liberal doses of K had been found to reduce Fe toxicity and increase yields.

Kalita *et al.* (2002) evaluated the effects of K (0, 10, 20, and 40 kg K₂O ha⁻¹) on the growth and yield of rice. They found that the application of 20 kg K₂O ha⁻¹ resulted in higher number of effective tillers m⁻² and grains panicle⁻¹ than other doses.

Mathad *et al.* (2002) conducted a field experiment in Bangalore, India, during *Kharif* 1988-89 to determine the effect of tillage, drainage practices and levels of potassium (0, 50, 75 kg K₂O ha⁻¹) on yield and crude protein content of rice cv. Jaya. Application of 50 kg K₂O ha⁻¹ significantly increased the grain yield (47.80 q ha⁻¹) and crude protein content of grain (6.26 per cent) and straw (2.94 per cent). Providing drainage under puddle conditions with application of potassium resulted in the removal of toxic substances, increased root activity and better nutrient uptake.

Meena *et al.* (2003) conducted a field experiment at the Indian Agricultural Research Institute, New Delhi, India to study the productivity and economic of *Oryza sativa* L. as influenced by K application. The experiment was laid out in split plot design with two levels of potassium, *viz.*, 62.5 and 125 kg ha⁻¹. Significantly higher total number of tillers, dry matter accumulation, grain and straw yields were

recorded with the application of 62.5 kg K ha⁻¹ applied in 2 equal splits (half at transplanting + half at the maximum tillering stage).

Abdel *et al.* (2004) conducted an experiment at EL-Sirw Agricultural Research Station Farm (Egypt) to evaluate the effects of five potassium nutrient levels (0, 57, 114, 171 and 228 kg K₂O ha⁻¹) on growth and yield of two rice cultivars (Giza 178 and Sakha 101) in 1998 and 1999 rice seasons in clay soils. Potassium had significant effects on dry matter content, yield and yield attributes as well as Na per cent, K per cent and Na/K ratio whereas most of the studied characters significantly increased with increasing potassium level up to 171 kg K₂O ha⁻¹. Moreover, increasing potassium level promoted K uptake against Na and decreased Na/K ratio, thereby improving rice growth, salt tolerance, productivity and net profit. Varietal differences were detected in all studied characters.

Arivazhagan *et al.* (2004) conducted a field experiment to investigate the effects of the split application of different potassium fertilizers (muriate of potash and sulphate of potash) on the yield and nutrient uptake by rice cv. PY5. The highest mean grain yield was obtained from MOP treated plots in both seasons.

Das and Panda (2004) Carried out a field experiment to study the effects of N (0, 60, 120 or 180 kg ha⁻¹) and K (0, 40, 80 or 120 kg ha⁻¹) on the growth rate of hybrid rice 6102. K (K₂O) was applied during transplanting. Crop growth rate (CGR) was greatest at 40 to 60 DAT and lowest at 20 to 40 DAT. At 40 to 60 DAT, the highest CGR was obtained with 80 kg K₂O ha⁻¹. At 60 to 80 DAT, CGR increased up to 120 kg K₂O ha⁻¹. CGR in response to N and K followed a parabolic path, *i.e.*, low at 20 to 40 DAT increased at 40 to 60 DAT then decreased at 60 to 80 DAT.

Kumar *et al.* (2004) conducted an experiment to evaluate the performance of rice cv. ADT 36 under different fertilizer schedules of N, P and K were supplied @ 120, 60 and 30 kg ha⁻¹ respectively, while organic manures were supplied @ 12.5 t ha⁻¹. Potassium content in straw was higher in treatments receiving one of the organic manures with K @ 60 kg ha⁻¹ compared to other treatments. K uptake was higher in treatments receiving 120 kg N ha⁻¹ with one of the manures compared to other treatments.

Yadav *et al.* (2004) conducted the field experiment to see the effects of the split application of K on yield and uptake of nutrients by rice hybrids. The rice hybrid recorded 50.13 q ha⁻¹ and 13.66 per cent higher grain yields compared to RTNRH-3 respectively. Potassium applied in three splits was superior to other application times regarding K uptake by grain and straw and total K uptake.

Arivazhagan and Ravichandran (2005) conducted field experiment with rice cv. IR 20 in Annamalainagar, Tamil Nadu, India. There were 6 treatments with 4 different fertilizer schedules. (100:50:50, 100:50:75, 150:50:50 and 150:50:75 kg NPK ha⁻¹). Application of 150:50:75 kg NPK ha⁻¹ resulted in the highest number of panicles hill⁻¹ (9.06), panicle length (19.6 cm), 1000 grain weight (20.50g), grain yield (5.06 t ha⁻¹) and straw yield (6.10 t ha⁻¹). Split application of K₂O resulted in the highest grain and straw yields (5.35 and 6.74 t ha⁻¹).

Mukherjee and Sen (2005) carried out an experiment during the Kharif season to study the effects of rice husk and fertilizer levels of potassium on growth and yield of rice. The application of potassium significantly improved plant height, number of tillers hill⁻¹, dry matter accumulation and chlorophyll content and leaf area index. Rice husk and fertilizer levels had significant and positive effects on grain and straw yields.

Dwivedi *et al.* (2006) conducted an experiment to see the effect of potassium levels on growth, yield and quality of hybrid rice. They observed that 80 kg K₂O ha⁻¹ was found better in obtaining higher production. Application of potassium increased the protein content in rice grains significantly.

Singh *et al.* (2006) conducted an experiment in a silt loam soil to evaluate the effect of potassium and potassium levels on growth, yields and seed quality of hybrid rice. They reported that 80 kg K₂O ha⁻¹ was found better to obtain higher production and good quality of hybrid rice.

Krishnappa *et al.* (2006) reported that increasing K rates increased paddy yields. Potassium applied in split dressings were more effective than when applied at transplanting time. Applied potassium fertilizer with organic manure increased soil K availability, K content and the number of grains panicle⁻¹, split application of increased soil K availability, K content in grain and straw. They also found that progressive higher content uptake of K resulted from increasing levels of its supply.

Bahmariar *et al.* (2007) described the effects of the different amount of nitrogen and potassium on yield and chemical compound of two rice cultivars. Four levels of nitrogen fertilizer (0, 50, 100 and 150 kg N ha⁻¹) and four levels of potassium (0, 75, 150 and 225 kg K₂O ha⁻¹) were applied. Nitrogen was applied at three different stage of plant growth, 1/3 at transplanting, 1/3 at tillering and 1/3 at booting stage and potassium was applied at two growth stages (1/2 at transplanting and 1/2 at growing stage). Results indicated that nitrogen application increased plant height, number of grains per panicle, grain yield. Amount of dry matter, biological yield, harvest index, 1000 grain weight and reduced the percentage of hollow grain.

Also applied potassium had positive effects on yield (6.8 t ha⁻¹) mentioned above components except harvest index and 1000 grain yield.

Kavitha *et al.* (2008) studied the effect of nitrogen and potassium management on the nutrient uptake, yield of hybrid rice and showed that the application of N and K in 4 equal splits at the active tillering, Panicle initiation, booting and flowering stages gave highest grain yield during the *Kharif* (7484 kg ha⁻¹).

Gobi *et al.* (2008) evaluated the establishment methods and split application of N and K fertilizer and growth analysis, NPK uptake. Nitrogen use efficiency and soil fertility status of CoRH2, Rice hybrid. They found that stand establishment methods a split application of N and K significantly influence the days needed for completion of 50 per cent flowering, crop growth rate and uptake during flowering.

Mostofa (2009) conducted a pot experiment in the net house of Department of Soil Science, Bangladesh Agricultural University, Mymensingh. Four level of potassium (0, 100, 200, and 300 kg K ha⁻¹) were applied. He observed that the yield contributing characters like plant height, tiller number, and dry matter yield were the highest in 100 kg K ha⁻¹.

Das *et al.* (2009) conducted a field experiment with four levels nitrogen (0, 60, 120 and 180 kg ha⁻¹) and four levels of potassium (0, 60, 120 and 180 kg ha⁻¹) during *Kharif* season of 2003 on growth and yield of hybrid rice (*Oryza sativa* L.). Attributing characters, grain and straw yield, and protein content up to 180 kg ha⁻¹ was increased. All the growth, developmental and yield characters were also significantly influenced by the application of potassium up to 80 kg K₂O ha⁻¹.

Wang *et al.* (2011) carried out a field experiment to study the effects of N, P and K fertilizer application on grain yield, grain quality as well as nutrient uptake and utilization of rice to elucidate the interactive effects among N, P and K in a field experiment with four levels of nitrogen (N), phosphorus (P) and potassium (K) fertilizers. The results showed that the application of N, P and K fertilizer significantly increased grain yield, and the highest yield was found under the combined application of N, P and K fertilizer.

2.2 Available potassium status

Ghosh and Hasan (1976) reported that nearly one fifth of the districts of India measured low available potassium and most of these were located in regions dominated by red lateritic soils. Even soils marked as a medium, later on, turned to be low in available K.

The rate and magnitude of the release of potassium are influenced by the degree of exposure of edges of the minerals to the soil solution and the position of exchangeable K concerning the outer layers (Sparks, 2000).

Pal *et al.* (2001) noticed the low status of potassium in lateritic soils of Cuttack district, similarly in some red and lateritic soils of West Bengal by Das *et al.* (2000). Totawat *et al.* (2001) reported potassium availability from soil to plants primarily depended on the nature and properties of K-bearing minerals in the soil. Though, feldspar is considered to be the major source of K reserve, weathering and release of K^+ from it was a slow process, contributing very little towards the soil pool of K, which could be utilized by the plants. Micas (muscovite and biotite) are considered as an important source of K in the soil for plant growth since their weathering released K^+ into the soil solution.

In Karnataka, about 27, 50 and 33 per cent of the total cropped area recorded low, medium and high K status respectively in the 1970s, whereas, subsequent soil test information indicated only 61 per cent of total samples analyzed were rated as high in K status (Motara, 2002).

Jonnie White (2002) found that the immediately available K pool in the soils was the most important source of soil K, and was poorly buffered by slowly available non-exchangeable K.

Yilmaz *et al.* (2005) reported that the values for available potassium ranged from moderately low ($59 \text{ mg K}_2\text{O kg}^{-1}$) to very high ($989 \text{ mg K}_2\text{O kg}^{-1}$) in the soils that are dominantly either clay loam or clay in structure. The available potassium in the top soils is generally in very good supply. It decreases rapidly with depth. Further, he opined that the illite content of soils could be used as a criterion to determine the potassium availability status of soils.

Srinivasa Rao and Vittal (2007) analysed the soils of different AICRPDA centres and reported that alluvial soils of Agra (UP), Hoshiarpur (Punjab) and Rakh Dhansar (Jammu and Kashmir), red lateritic soils of Bangalore (Karnataka) and deep red soils of SK Nagar (Gujarat) have recorded low K status.

Datta (2011) reported that out of the 109 soil series, 17.5 per cent were low, 40 per cent were medium and 42.5 per cent were high in available K and low fertility soil series were reported to occur mainly in states of Punjab, West Bengal, Karnataka, Rajasthan, Maharashtra and Madhya Pradesh.

Naidu *et al.* (2011) reported that the available K status in Indian soils showed a shift from medium to high in 1960 to 1970s and now medium to low. Studies on long-term changes in K status in Karnataka showed that taluks of Hoskote

(Bangalore district), Khanapur, Belgaum, Athni, (Belgaum district), Kudligi (Bellary district), Bijapur, Indi (Bijapur district), Sringeri (Chikmagalur district), Shirahatti (Dharwad district), Shapur (Gulbarga district), Mercara, Virajpet (Kodagu district), Honnavar and Siddapur (U.Kannada district), undergone a decline in K status either from high to medium or medium to low status.

Singh and Mishra (2012) reported that the available potassium status in the soils ranged between 134.6 to 310.4 kg K₂O kg⁻¹ and positive correlation between available potassium and soil pH.

Sannappa and Manjunath (2013) reported that the available potassium content is medium to high in most of the soils of Karnataka except in lateritic soils of the coastal plain and the Western Ghats. Highest available potassium content was recorded in Kodagu region (538 kg K₂O kg⁻¹) when compared to other regions of the Western Ghats of Karnataka (Dakshina Kannada, Udupi and Chikmagalur).

Sharma (2013) reported that the available potassium content of the soils varied from 67.7 to 120.8 mg K₂O kg⁻¹ with a mean value of 91.9 mg K₂O kg⁻¹ in soils of Dimapur, Nagaland.

Kundu *et al.* (2014) noticed that the available potassium towards total potassium for surface soils ranged from 0.56 to 0.77 per cent, with a mean value of 0.65 per cent. The contribution of the available potassium towards total potassium for subsurface soil was ranged from 0.58 to 0.80 per cent, with a mean value of 0.68 per cent.

Rajashekar Rao (2015) reported that the available K content varied widely and ranged from 2.3 mg K₂O kg⁻¹ to high as 369 mg K₂O kg⁻¹ in soils of Papua, New Guinea.

2.3 Forms and distribution of potassium in soils

Patriam and Prasad (1983) observed that the release of non-exchangeable K has been used to evaluate the long term K supplying power of soil. Wheat crop utilized about 86 per cent of the total K uptake from non-exchangeable sources (Krishna Kumari *et al.*, 1984). But this contribution was negligible when K fertilizer was applied. At higher levels of K application, there was a build up in the non-exchangeable K. when no K was applied, the crop utilized about 95 per cent of the K from non-exchangeable sources and it decreased to 59 per cent at 53.5 mg kg⁻¹ soil and 13 and 22 per cent at 107 and 160.5 mg kg⁻¹ levels respectively.

Martin and Sparks (1985) classified the different forms of soil potassium based on the location in the soil system such as water-soluble K in soil solution,

exchangeable K on colloidal exchange sites of clay and organic matter, non-exchangeable K in the interlayer of dioctahedral mica, trioctahedral mica, hydrous mica, chlorite-vermiculite integrated and interstratified mica and K-feldspar.

Subba Rao and Sekhon (1987) reported that the potassium status of five soil series from Eastern India which were under intensive rice-rice and rice-wheat cropping systems. They found that in soil of Hangram series high available K was associated with comparatively low reserve form. These soils dominated by smectite maintained a higher available K than those of Balishi (Orissa) and Kharbona (West Bengal) once which were predominately Kaolinitic.

There was a decreasing trend in exchangeable K with continuous cropping and the decrease was found to be more pronounced during the first crop than later crops in succession started removing K from non-exchangeable fractions after a substantial part of exchangeable K was exhausted (Patiram and Prasad, 1983 and Chakravarthi and Patnaik, 1990).

Bhake *et al.* (1992) made an extensive study on distribution pattern of different forms of soil potassium in extensively rice growing areas *viz.*, Chandrapur, Umared and Dapoli districts of Maharashtra state reported that water soluble K ranged from 0.24 to 0.62 mg K₂O 100 g⁻¹ of soil in umared soils, while Dapoli soil contained slightly more water soluble (0.42 to 1.25 mg K₂O 100 g⁻¹ soil). All the other forms of K however, were higher in Chandrapur and Umared soils than Dapolic soils, the exchangeable K ranging from 12.1 to 18.80 mg K₂O 100 g⁻¹ soil in the latter. The exchangeable K was the predominant sources of available K in all the soils and available K of Dapoli was significantly and positively correlated with total K, lattice K and exchangeable K, while in Chandrapur soils it was significantly and positively correlated with exchangeable K only. In Umared soils, available K was significantly and positively correlated with total K and exchangeable K.

2.3.1 Water-soluble potassium

Potassium present in soil solution as the soluble cation is termed as water-soluble K which is readily absorbed by the plants and relatively unbound by cation exchange forces and invariably subjected to leaching losses in relation to soil properties (Ramanmoorthy and Velayutham, 1976). Application of higher dose of potassium increased the concentration of K in the soil solution to a higher extent in sandy laterites compared to that of clayey soils (Bandhyopadhyaya and Goswamy, 1988).

Singh *et al.* (1983) reported that the distribution of water-soluble potassium is related to the type of vegetation, texture, amount of exchangeable and non-exchangeable potassium present in the soil.

A positive correlation was noticed between water-soluble K and soil reaction in alluvial and lateritic soils of Assam (Basumantry and Bardolui, 1992). At a given level of exchangeable potassium, a smaller amount of potassium was present in water-soluble form (Sidhu and Bhangu, 1993).

Upon water logging, the amount of water-soluble K increases as a result of exchange reaction due to increase in Fe^{2+} and Mn^{2+} concentrations due to the reduction of Fe and Al compounds in soils (Verma *et al.*, 1994).

Raskar and Pharande (1997) observed a higher content of water-soluble K in the surface layer of some *Alfisols* and reported that the high status of K was due to the intense pedochemical weathering, higher organic carbon content and release of liable K from organic residues in soils.

Manjunatha (2000) reported that the mean water soluble K content in soils under different crop growing areas of Karnataka decreased in the order of Ramanathapura > Shivamogga > Periyapatna > Hunsur > H.D.Kote.

Kadalli *et al.* (2001) found that in soils belonging to coastal zone of Karnataka, the water-soluble K in the profile varied from 0.02 to 0.04 cmol (P^+) kg^{-1} . It contributed 14.28 per cent towards the total available potassium. The lower potassium in these soils might be attributed to the presence of sesquioxides, kaolinite type of clay minerals with a low cation exchange capacity (CEC).

Srivastava and Shyam Singh (2001) reported that water-soluble K under the soils of mandarin-growing areas of Nagpur was much higher in black soil (24-53 mg K kg^{-1}) than of red soil (3-13 mg K kg^{-1}).

Victor *et al.* (2004) noticed that the water-soluble K in soils ranged from 0.013 to 0.092 cmol(p^+) kg^{-1} with a variability of 66 per cent, the water-soluble K was found as lowest form extracted from all these soils and concluded that the soils from the forest-savanna transition and coastal savannah zones had relatively higher soil solution K concentration than soils from the moist rainforest and semi-deciduous forest zones. Also, soils of the semi-deciduous forest and forest-savannah transition, as well as the coastal savannah zones, contained 2 to 3 times exchangeable K of the soils of the moist rainforest.

Singh *et al.* (2006) found that the water-soluble K ranged from 9.20 to 26.8 mg K kg^{-1} with an average of 1.71 mg K kg^{-1} . The distribution of potassium fractions in relation to land forms in a Himalayan catena. The water-soluble

K ranged between 4.0 to 18.5 mg K kg⁻¹. It was positively correlated to silt and negatively to sand. The positive coefficients of correlation amongst the forms of K suggested that K forms are present in dynamic equilibrium with each other in soils (Sharma *et al.*, 2006).

Chatterjee and Sanyal (2008) found wide variability in soil K fractions in selected rice growing soils in the alluvial tract of West Bengal. Several studies on potassium variability in the alluvial, red and lateritic soils of West Bengal and Jharkhand showed that the variability of available potassium in soil is quite high among fields within villages.

Shivanna (2008) reported that the soils belonging to sandy loam to sandy clay texture and water-soluble K in soils varied from 6 to 12 mg K kg⁻¹, respectively.

Osernwota *et al.* (2010) reported that in twenty composite surface (0-15 cm) and sub-surface (15-30 cm) soil samples collected from different locations of Central Southern Nigeria, the water-soluble K content ranged from 1.3 to 18.00 mg K kg⁻¹. Clay was negatively and significantly correlated with water-soluble K ($r = 0.43^{**}$). The distribution of potassium in these soils appeared to be influenced by parent material. Similarly, Ramesh Babu (2011) noticed that the water-soluble potassium in surface soils varied from 9.85 to 13.00 mg K kg⁻¹.

Raheb and Heidari (2012) noticed that the mean water soluble and exchangeable K in paddy soils were rather low compared to non-paddy soils due to potassium fertilization in non-paddy soils. Non-exchangeable potassium in the samples containing smectite as a dominant clay mineral was lower than the samples dominated by vermiculite, hydroxyl-interlayer vermiculite and illite.

Narayan Rao *et al.* (2013) observed that higher water soluble potassium in surface layer than that of subsurface layers due to more exposure of potassium bearing minerals to weathering and (or) upward translocation of K from subsurface layers by the capillary rise or due to the addition of potassium through plant residues, manures and fertilizers.

2.3.2 Exchangeable potassium

Exchangeable K is the portion of the soil K that is electrostatically bound as an outer sphere complex to the surfaces of clay minerals and humic substances. It is exchanged with other cations and also is readily available to plants. The release of exchangeable K into the soil solution is called desorption and the reverse reaction is termed as adsorption.

A variety of extracting solutions *viz.*, neutral unbuffered electrolyte solutions and weak or strong acid solutions are in use to measure exchangeable K. Exchangeable K represents the fraction adsorbed on external charge sites and the accessible internal surface of clay colloids. So, it is mainly the clay content and the clay mineralogy which modifies the availability of exchangeable K (McLean, 1978).

An increase in exchangeable potassium in subsoil horizon due to leaching of potassium from the surface horizon in coastal acidic soils indicating downward movement of applied potassium, which resulted in the accumulation of potassium in the clayey subsoil (Sparks, 1980). For given clay content, the proportion of HNO₃ extractable potassium was lowest in kaolinite, than mixed and smectite soils (Sharpley, 1989).

Lateritic soils of Andhra Pradesh contain a very small proportion of exchangeable K, which was attributed to the high proportion of hydrogen ions exchange complex (Subba Rao *et al.*, 1984). Similarly, acid soils of West Bengal and Orissa showed a very high ratio between exchangeable K and water-soluble K indicating comparatively stronger bonding energy of K with soil colloids (Bandhyopadhyay *et al.*, 1988).

Brar *et al.* (1986) reported that soil solution K was regarded as a function of exchangeable K present in illitic and kaolinitic soils. Sharpley (1989) observed that a close relationship between water-soluble K and exchangeable K and in turn released it to 1N HNO₃ extractable K and concluded that exchange and HNO₃ extractable K give a better indication of the potential K supplying power of the soil.

Exchangeable K in two soil series of south Kerala was positively correlated with water-soluble, available, lattice bound and total potassium (Sudharamai Devi *et al.*, 1990). Whereas Das *et al.* (1993) observed that positive correlation between exchangeable K and silt plus clay in some pedons of Rajasthan.

Cervantes and Hanson (1991) opined that exchangeable K would estimate the easily available K but failed to estimate the long-term capacity of the soil to release K. The average exchangeable K status in Entisols was 0.107 cmol(p⁺) kg⁻¹, 0.11 cmol (p⁺) kg⁻¹, In Inceptisols and 0.134 cmol (p⁺) kg⁻¹ in Alfisols of Assam (Boruah *et al.*, 1992).

Das *et al.* (1993) reported that Lithic Ustorthents of Rajasthan contained low exchangeable K mainly due to high sand content.

Venkatesh and Sathyanarayana (1994) observed that the exchangeable K was positively correlated with clay, pH and CEC but negatively with sand and silt content in some *vertisols* of North Karnataka.

Zubillaga and Conti (1994) stated that contribution of textural fractions on exchangeable K were 70 and 80 per cent, 8 to 18 per cent and 1 to 10 per cent clay, silt and sand, respectively indicating the influence of CEC of the minerals involved in addition to the amount of clay present in the soil.

Raskar and Pharande (1997) observed that higher exchangeable K in surface layer than that of subsurface layers due to higher crop residue yielding higher humus content and potash fertilizer application in the surface layer and variation in clay content.

The soils under alpine vegetation of their Garhwal had the high amount of exchangeable potassium and ranged from 0.4 to 1.7 me 100 g⁻¹ soil in surface and decreased with depth (Murthy and Sharma, 1999).

Manjunatha (2000) reported that the content of exchangeable potassium in surface soils varied from 30 to 135 mg K kg⁻¹ and represented on an average 0.67 per cent of total K present in the sample. Further, exchangeable K fraction showed a significant and positive correlation with available potassium ($r = 0.860^{***}$).

The non-exchangeable K was significantly and positively correlated with CEC ($r = 0.802^{**}$), Clay ($r = 0.842^{**}$) and silt ($r = 0.523^*$) content and negatively correlated with sand content ($r = - 0.791^{**}$) as reported by Das *et al.* (2000) and Chand and Swami (2000).

Minimal exchangeable K in particulate soil is fixed and it is controlled by the amount and nature of mineralogy, seems a good indication of soil K fertility, Srinivasa Rao *et al.* (2002). Kapto Singh *et al.* (2001) reported that the exchangeable K ranged from 39 to 100 g K kg⁻¹ and was maximum in surface horizon. Similarly, Sharma *et al.* (2006) studied the distribution of potassium fractions in relation to land forms in a Himalayan catena. The exchangeable K ranged between 27.3 and 292.2 mg K kg⁻¹ and positively correlated with clay and CEC of soils.

Twenty composite surface (0-15 cm) and sub-surface (15-30 cm) soil samples collected from different locations of central Southern Nigeria, the exchangeable K content ranged from 7.2 to 115 mg K kg⁻¹. The distribution of K in these soils appeared to be influenced by parent material, its deliria of weathering, pH and ninety per cent of the soils were deficient in exchangeable K as reported by Osernwota *et al.* (2010).

2.3.3 Non-Exchangeable potassium

Non exchangeable K is a form of K barring the water soluble K and readily exchangeable form of K. This form of K is not readily available to plants. It is distinct from mineral K in that it is not bonded covalently within the crystal structure of the soil mineral and trioctahedral micas, vermiculite and mixed clay minerals (Rich, 1972). Non-exchangeable K ions are strongly held by the negatively charged inter layer surface sites (Kittrick, 1966). Victor *et al.* (2004) reported that non-exchangeable K constituted the dominant fraction and ranged from 0.026 to 0.996 cmol (p⁺) kg⁻¹ with a mean of 0.371 cmol (p⁺) kg⁻¹.

Sparks (1980) stated that the non-exchangeable K might be released into the soil solution as the K concentration in soil solution and exchangeable K decrease due to crop uptake or leaching. The exchangeable K and non-exchangeable K levels comprise a small portion of the total K. The bulk of total soil K is in the mineral form (Sparks and Huang, 1985).

Ningappa and Vasuki (1989) obtained low K fixation ranging from 21.4 to 40.6 per cent on acidic soils of Western Ghats of Karnataka. The low fixation of these soils was attributed to the 1:1 type of clay minerals and low pH values.

Yadav and Singh (1999) reported lower non-exchangeable K in surface horizons was due to leaching losses. Further, clay and silt showed significant positive correlation with fixed K in these soils. Non-exchangeable K (fixed K) is only released to the exchangeable pool when the level in exchangeable and soil solution pool is depleted by either crop removal or other factors like crop leaching (Tisdale *et al.*, 1993)

Arabindar and Saroj Kumar (2000) observed that the cumulative release of non-exchangeable K by repeated extraction with boiling 1N HNO₃ followed a semi-logarithmic behavior with increasing number of extractions, suggesting that the release of non-exchangeable K decreased with a successive number of extractions. The reserves of step K content were in general related to the content of the clay fractions of the soils.

Hirekurabuar and Satyanarayana (2000) revealed that there was a wide variation in the distribution of non-exchangeable K in soils under cotton based cropping system in Karnataka. This variation could be due to differential uptake of K by a deep-rooted cotton crop, trap non-exchangeable K from deeper layers. This might have resulted in lower value in subsurface than the surface, on an average, it constituted 7.40 per cent of total K.

Kadalli *et al.* (2001) reported that non-exchangeable K in the soils varied from 1.1 to 0.2 cmol (p⁺) kg⁻¹. It contributed 1.3 to 5.23 per cent of total K in cashew growing soils in the coastal zone of Karnataka.

Soils with a high content of 2:1 clay minerals (micas, vermiculite and high layer-charge smectite) contain larger amounts of non-exchangeable K than those with kaolinite and other siliceous minerals (Ghosh and Singh, 2001).

Singh and Chauhan (2001) reported that the contribution of exchangeable and non-exchangeable K was found to be almost similar towards meeting K requirements of most crops. The release of non-exchangeable K was non-significantly correlated with some physic-chemical properties namely, pH, EC, OC, CaCO₃, sand silt and clay but, it was positively correlated with cumulative dry matter yield ($r = 0.591^{**}$) and cumulative K uptake by plants ($r = 0.784^{**}$).

Gangopadhyaya *et al.* (2005) reported that maximum K content of the soils was found to be in the non-exchangeable forms, mostly fixed up with in the clay lattice rendering very small amount available to plants as evident from the low amount of the neutral normal ammonium acetate extractable K. The non-exchangeable K pool is an important reservoir of K in soils and K released from this pool is an important reservoir of K in soils and K released from this pool can contribute up to 80 to 90 per cent of K supply to plants (Barre *et al.*, 2007).

Soil solution and exchangeable K must be replenished continuously by the release of K from the non-exchangeable pool (Jalali, 2006). Potassium release from non-exchangeable K form is influenced mainly by type and amount of clay and concentration of different K forms in the soil (Jalali, 2006 and Simenson *et al.*, 2007).

Ramesh Babu (2011) noticed that the exchangeable potassium content in surface soils ranged from 124.76 to 170.87 mg K kg⁻¹, while mineral potassium content ranged from 1.35 to 1.60 percent in soils.

2.3.4 Mineral potassium

Bear (1958) reported that important minerals which contain K are Illite (4-7 %), orthoclase (9-15 %), albite (up to 4 %), muscovite (8-11 %), biotite (6-9 %), hornblende (1-3 %) and montmorillonite (up to 0.5 %) similarly, Sidhu and Dhillon (1985) reported that muscovite, biotite, Microline and orthoclase were found to be the K bearing minerals present in sand fractions. Micas, orthoclase and Microline occurred in silt, while illite was found in clay fractions.

The direction of O-H bond as well as the tetrahedral rotation, tilting may favor rapid release of potassium from trioctahedral micas such as muscovite

(Rich, 1968). The fraction potassium from feldspar increased with increase in particle size, whereas the reverse trend was true for a fraction of potassium from micas (Sparks, 1987).

The rate of potassium release from potassium-bearing minerals depends on (1) total amount of potassium present, (2) Specific surface, (3) Crystallinity or stage of degradation, (4) Chemical composition. Therefore, finer particles of clay released more potassium rapidly during weathering, however, depending on mineralogical makeup (Datta and Shastry, 1993).

Kadalli *et al.* (2001) reported that the lattice K was higher in the Ap horizon compared to B horizon, which may be probably due to a slight decrease in the content of finer fraction in the subsurface horizon and lattice K formed 93.57 per cent of the total potassium in soils of the coastal zone of Karnataka.

Kuldeep Singh *et al.* (2001) reported that exchangeable, non-exchangeable, lattice and total K fraction were significantly correlated with clay indicating it's the reservoir of K in soils. Lattice K recorded a poor relationship with exchangeable K. this would imply the poor replenishment of exchangeable K from lattice K.

Mukhopadhyay and Datta (2001) reported that the lattice K recorded as dominant fraction compared to other fractions of K in soils. This is probably due to the presence of potassium bearing minerals in soils. In general, more than 90 per cent of the total K in the soils is found in mineral form as structural (Pasricha, 2002).

Musthaq Wani and Raj Kumar (2008) noticed that the lattice potassium ranged from 11770.20 to 17284.80 mg K kg⁻¹ with a mean value of 14730.30 mg K kg⁻¹. The per cent contribution towards total potassium ranged from 95.5 to 95.7 per cent, with a mean value of 95.60 per cent. Similarly, Anil Sharma *et al.* (2009) also observes the per cent contribution of mineral K to total K in soils was more than 90 per cent, thus indicating the dominance of this form over other forms of K.

Mineral's K release to soluble and exchangeable form and its adsorption by exchange sites depends on the equilibrium, between different phased of soil K, which may be affected by such factors as root uptake, applied fertilizer K, soil moisture, soil pH and soil temperature (Britzke *et al.*, 2012).

Lalitha and Dakhshinamoorthy (2014) stated that micas and feldspars curring predominantly in sand and silt fractions of soil are major sources of reserve K. Small amounts of feldspars and micas present in fine sand and silt fractions might serve as a source of slowly-available K.

2.3.5 Total potassium

A significant positive correlation between total K, sand, Silt and Clay in some vertisols of North Karnataka was observed by Venkatesh and Sathyanarayana (1994).

Prasad *et al* (1967) reported that the content of total K varied with the presence of K bearing minerals like feldspar, micas and illite. The total availability of K was found to be dependent on the extent of weathering minerals (Chahal *et al.*, 1976). Though it gives us an idea of the content of soil potassium, yet all of it is not readily available to the plants. It constitutes 97 to 98 per cent of the total K in soil (Attoe and Trough, 1945).

Vertisols had higher total K concentration followed by water-logged soils and lateritic soils. Potassium fractions in soils exist in equilibrium with each other. Upon water logging, the amount of water-soluble K increases as a result of exchange reaction due to increase in Fe^{2+} Mn^{2+} concentrations (Verma *et al.*, 1994). Further, it was noticed that total K was significantly correlated with clay in normal soils of Uttar Pradesh (Singh and Agarwal, 1995).

The total K content in Alfisols soil series was very low (<1 %) which might be due to the low content of K bearing minerals in the basaltic alluvial soils of Maharashtra (Raskar and Pharande, 1997).

Boruah *et al.* (2002) noticed that total extractable K was positively correlated with non-exchangeable K, lattice K and total K. Total extractable K per cent was positively correlated with non-exchangeable K: lattice K ratio, which might be due to the weaker binding energy of K at the non-exchangeable sites than those inside the crystal lattice resulting in easier release of K from the non-exchangeable form.

Total potassium recorded significant positive correlation with mineral potassium ($r = 0.99^{**}$). Much of the total K in soil Deleware was found in the sand fraction of soils (Sparks, 2002).

Gangopadhyaya *et al.* (2005) observed that the total K varied from 0.20 to 2.11 per cent with a mean value of 0.8 per cent. The high total K content of these soils was attributed to the presence K bearing minerals in the soils.

Rajashekhar Rao *et al.* (2010) reported that the water-soluble K content constituted less than 1 per cent of the total K. exchangeable K content contributed to about 2.0 to 3.1 per cent of the total K, while, non exchangeable K contents were in the range if 2.5 to 4.2 per cent of the total K.

Suddhi Prakashan *et al.* (2010) noted that high soil clay contents with low soil pH are often associated with low total K concentration. The exchangeable K and non-exchangeable K levels comprise a small portion of the total K. the bulk of total soil K is in the mineral fraction (Steve Nake, 2010).

Ramesh Babu (2011) noticed that the total potassium content ranged from 1.39 to 1.64 per cent. Further, the data revealed that the per cent potassium fixation capacity for the surface soils varied between 10.16 and 27.34 per cent with a mean value of 17.15 per cent. Total potassium was recorded in the range of 1310 to 70,000 mg K kg⁻¹ and appeared to be low in Udupi district, coastal region of Karnataka (Leelavati, 2016).

2.4 Dynamic equilibrium among different forms of soil potassium.

A dynamic equilibrium exists between water soluble, exchangeable, non-exchangeable and mineral form K. the various forms of soil potassium are inter related and comprise a system in which an increase in one form occurs at the expense of one or more of the forms. The forms of soil K in the order of their availability to plants are in the order of solution > exchangeable > fixed (non-exchangeable) > mineral (Sparks, 2002).

While studying the crop response to applied potassium under different lime levels, Uttam Kumar Singh and Saroj Kumar Sanyal (2000) reported that the pH of both the treated soil increased sharply with increase in lime levels. All forms of soil K namely water soluble, exchangeable, non-exchangeable K and step K decreased with an increase in the level of lime application.

Levels of solution K were affected by the equilibrium and kinetic reactions that occur between the forms of soil K, soil moisture content and the concentration of bivalent cations in solution and on the exchangeable phases. (Sparks, 2002).

Sanyal and Majumdar (2001) reported that of the different forms of soil K, the soluble and exchangeable forms contribute to the pool of readily available K, while the non-exchangeable K serves as a reserve source of soil K. Only 1 to 2 per cent of total soil K is generally present as readily available forms in soil.

Britzke *et al.* (2012) stated that the release of mineral's K to soluble and exchangeable forms and its adsorption by exchange sites depends on the equilibrium between different phases of soil K, which may be affected by such factors as root uptake, applied fertilizer K, soil moisture, soil pH and soil temperature.

Amoakwah and Frimpong (2013) reported that the water-soluble K, exchangeable K measured in the soils ranged from 0.05 to 0.25 cmol (p+) kg⁻¹ and 0.26 to 0.89 cmol (P⁺) kg⁻¹ respectively. Water-soluble K and exchangeable K

concentrations positively correlated with organic matter, CEC and per cent bases saturation.

Sharma (2013) reported that the total K, $1\text{N NH}_4\text{OAc-K}$, water-soluble K, $1\text{N HNO}_3\text{-K}$ and $0.01\text{ M CaCl}_2\text{-K}$ ranged between 1641 to 3455, 61.3 to 130.0, 4.8 to 9.5, 865 in 1497 and 16.4 to 36.3 mg K kg^{-1} and $0.01\text{ M CaCl}_2\text{-K}$ constituted 3.7, 0.3, 45.1 and 1.1 per cent towards total K in these soils. Highly significant and positive relationship amongst different forms of K indicated the existence of dynamic equilibrium among various forms of K. all fractions of K were significantly and positively correlated with SOC.

Kundu *et al.* (2014) reported that amongst the different K forms, available K was highly and significantly correlated with water-soluble K ($r = 0.960^{**}$), exchangeable K ($r = 0.777^{**}$), non- exchangeable K ($r = 0.822^{**}$), total K ($r = 0.998^{**}$) and lattice K ($r = 0.997^{**}$). Similarly, results were also reported by Bhasker *et al.* (2001), Srinivasa Rao *et al.* (2002) and Setia and Sharma (2004). The positive and significant correlations between these forms of K with other forms indicate that the available K is governed by the other forms of potassium like non-exchangeable and total potassium.

Material and Methods

III MATERIAL AND METHODS

A field experiment was conducted at Zonal Agricultural and Horticultural Research Station (ZAHRS), Brahmavar, Udupi district, Karnataka during *Kharif* 2017-18 on paddy to know the available potassium status, distribution of potassium fractions and also uptake of potassium by paddy. The experimental site is situated at 13^o.43'23'84'' North latitude and 74^o. 73'51'72'' East longitude with an altitude of 10 meters above mean sea level.

Before the start of the experiment, initial soil sample of experimental site was collected, processed and analyzed for various properties and the results pertaining to initial soil sample analysis presented in Table 1 and monthly meteorological data was shown in Fig 1.

3.1 Treatment details

The experiment comprised of ten treatments combinations and details of the treatments are presented below and layout represented in Fig 2:

- T₁: 45 kg K₂O ha⁻¹ at basal
- T₂: 60 kg K₂O ha⁻¹ at basal
- T₃: 75 kg K₂O ha⁻¹ at basal
- T₄: 45 kg K₂O ha⁻¹ in two equal splits
- T₅: 60 kg K₂O ha⁻¹ in two equal splits
- T₆: 75 kg K₂O ha⁻¹ in two equal splits
- T₇: 45 kg K₂O ha⁻¹ in three equal splits
- T₈: 60 kg K₂O ha⁻¹ in three equal splits
- T₉: 75 kg K₂O ha⁻¹ in three equal splits
- T₁₀: No K is applied

Two equal splits- first at time of transplanting and second at 55- 60 DAT (Days after transplanting), three equal splits- first at time of transplanting, second at 25- 30 DAT and third at 55-60 DAT.

[Note: For all the treatments nitrogen & phosphorus nutrients (N: P = 60: 30 kg ha⁻¹) and FYM applied @ 10 tons/ha as per the package of practice].

Table 1: Soil physico-chemical properties of the experimental site

Parameters	Values		
pH (1:2.5)	5.01		
EC (1:2) (dSm ⁻¹)	0.020		
Texture	Sand (%)	49.80	Sandy Loam
	Silt (%)	42.53	
	Clay (%)	7.67	
Organic carbon (%)	1.25		
Available nitrogen (kg ha ⁻¹)	603.92		
Available P ₂ O ₅ (kg ha ⁻¹)	48.12		
Available K ₂ O(kg ha ⁻¹)	190.94		
Available sulphur (ppm)	25.46		
Exchangeable calcium (cmol[P ⁺]kg ⁻¹)	2.08		
Exchangeable magnesium (cmol[P ⁺]kg ⁻¹)	1.37		
DTPA extractable Fe (mg kg ⁻¹)	39.24		
DTPA extractable Mn (mg kg ⁻¹)	2.01		
DTPA extractable Cu (mg kg ⁻¹)	1.86		
DTPA extractable Zn (mg kg ⁻¹)	2.42		
Water soluble potassium (mg kg ⁻¹)	26.24		
Exchangeable potassium (mg kg ⁻¹)	70.68		
Non exchangeable potassium (mg kg ⁻¹)	301.71		
Lattice potassium (mg kg ⁻¹)	1417.43		
Total potassium (mg kg ⁻¹)	1816.06		

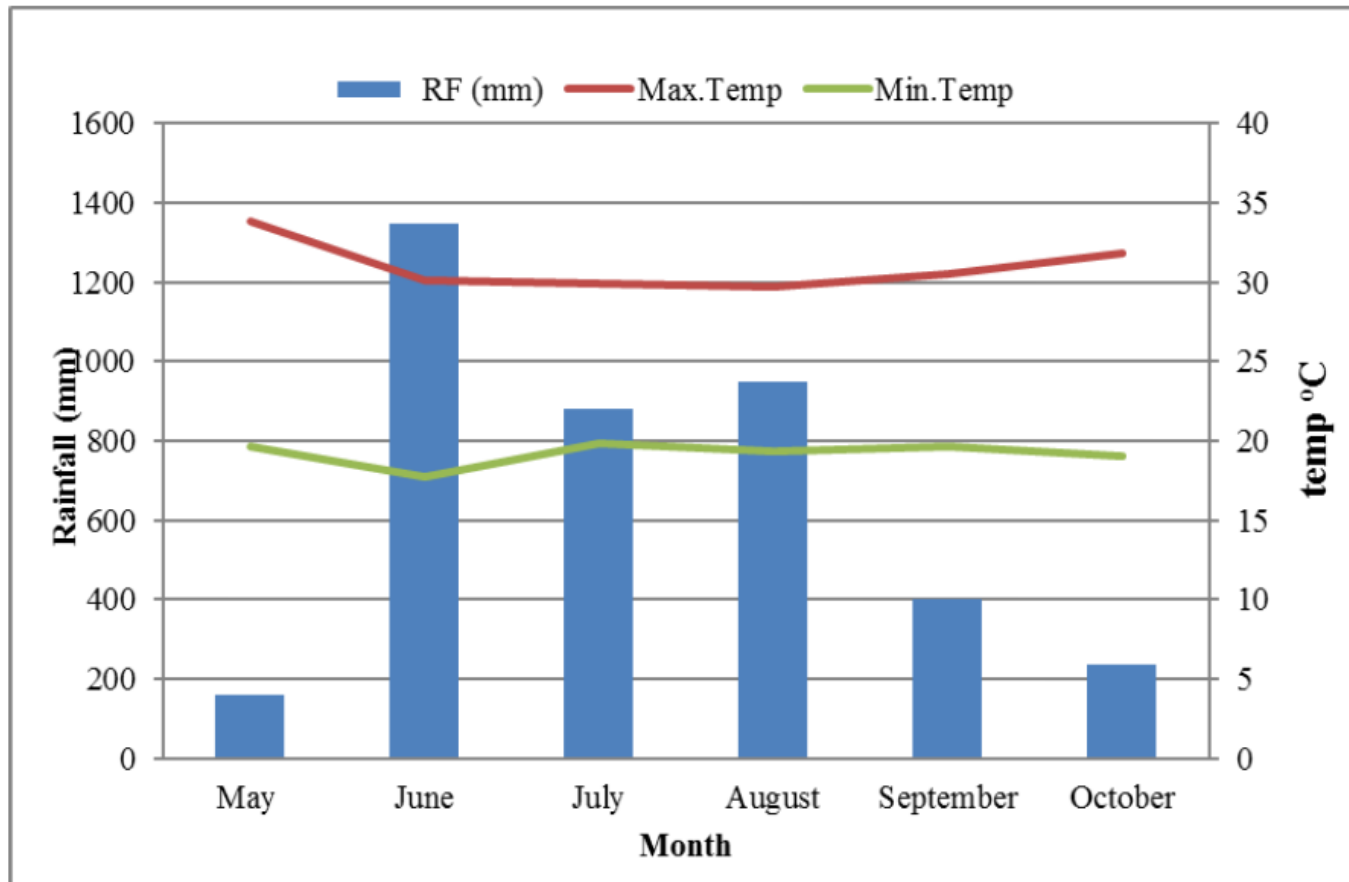


Fig 1. Monthly meteorological data for the experimental period *Kharif* 2017.

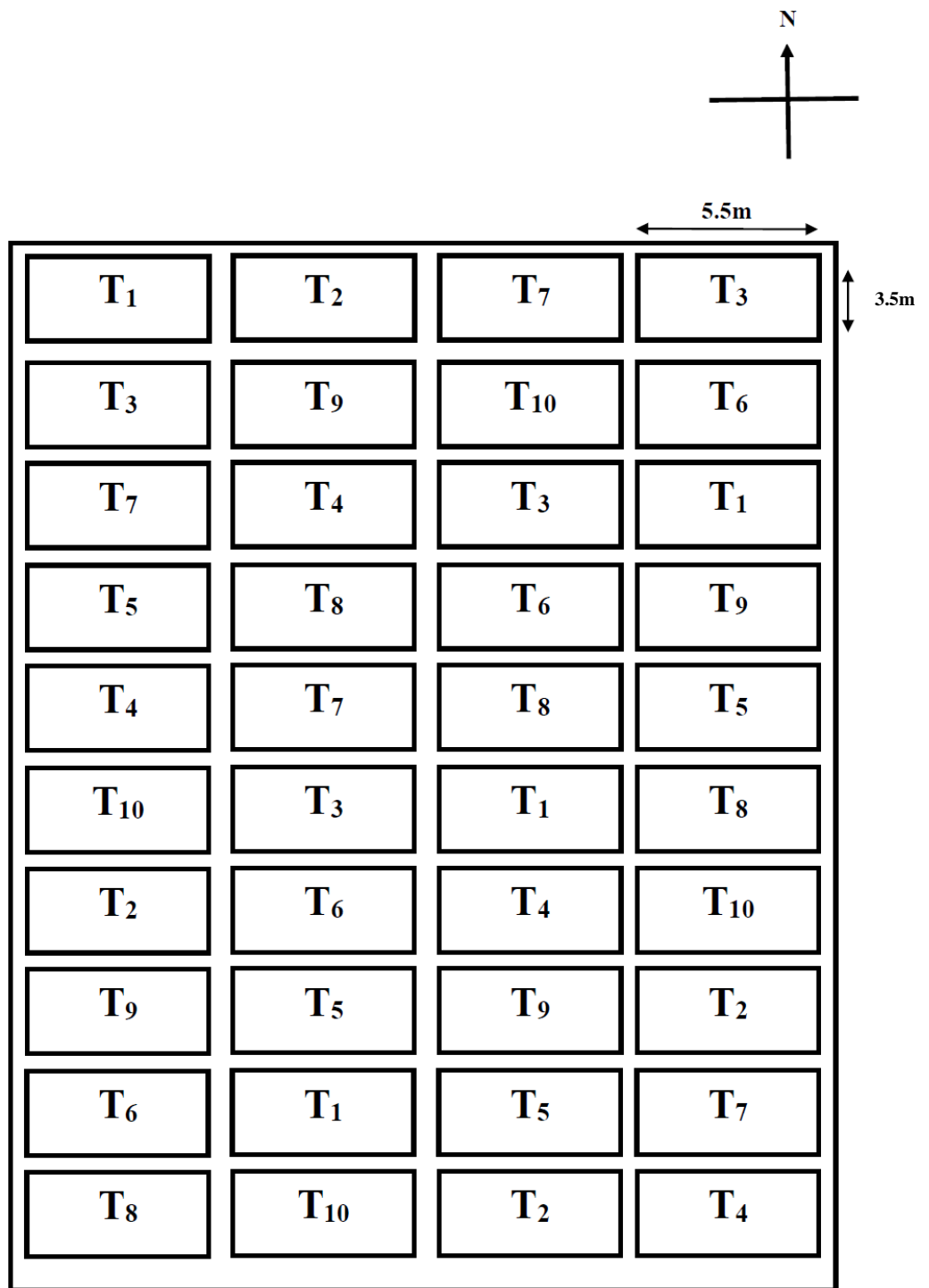


Fig 2: Plan of the layout of a field experiment

3.1.1 Crop details

Location: Zonal Agricultural and Horticultural Research station, Brahmavar

Crop: Paddy

Variety: MO-4

Season: *Kharif*

Design: RCBD

Treatment: 10

Replication: 4

Spacing: 20 cm X 25 cm

Gross plot: 5.5 m X 3.5 m

Net plot: 4.4m X 2.25 m

RDF: 60:30:60 (N: P₂O₅: K₂O kg ha⁻¹ and FYM 10 tons ha⁻¹)

3.2 Cultural operations

3.2.1 Land preparation

The land preparation made using tractor-drawn cultivator twice, followed by puddling twice with disc puddler and finally level using wooden plank.

3.2.2 Transplantation

Seedlings were selected from the nursery bed and were transplanted 14 days old seedlings with a spacing of 20 cm × 25 cm. Three seedlings were placed per hill during transplantation.

3.2.3 Weed management

Weeds in the experimental plots were removed by manual hand weeding at 15 days after transplanting and two hand weeding were carried out at 30 and 60 days after transplantation.

3.2.4 Water management

After transplanting up to 10 days, a thin film of water was maintained and thereafter 0 to 5 cm standing water was maintained up to 10 days before harvesting. Water was drained during top dressing and spraying of chemicals.

3.2.5 Fertilizer management

The recommended dose of fertilizers as per the treatments was applied as Urea, Rock phosphate and Muriate of potash (MOP) to supply N, P and K, respectively and Zinc was applied as zinc sulphate.

3.2.6. Plant protection measures

To control leaf folder and stem borer, Monocrotophos @ 1000 ml ha⁻¹ was sprayed at 25 and 50 days after transplanting and one spray of Streptomycin sulfate @ 60 g ha⁻¹ were taken up to control the bacterial leaf blight.

3.2.7 Harvesting and threshing

The crop was harvested at physiological maturity, threshed and cleaned manually. The plants in the net plot area were harvested treatment wise and kept separately for sun drying. Hand threshing and winnowing were done to separate the grains after sun drying.

3.3 Growth and yield observations

From the net plot, one m² area was selected and tagged to record various observations. Observations on growth parameters at different stages of crop growth viz., at maximum tillering stage (60 DAT) and at harvest were recorded observation on plants. Data on yield parameters were recorded at harvest.

3.3.1 Growth parameters

3.3.1.1 Plant height (cm)

Plant height was recorded at maximum tillering stage (60 DAT) and at harvest from the base of the plant up to the last sheath of the main shoot. Values of height were expressed in centimeter.

3.3.1.2 Total number of tillers per m²

The total number of tillers per m² were counted and mean was computed.

3.3.2 Observation on yield parameters and yield of rice

3.3.2.1 Panicle length (cm)

Length of panicle from one m² area selected in each plot was recorded from base to tip of panicles and the mean was computed and expressed in centimeters.

3.3.2.2 Number of filled and unfilled grains per panicle

Filled and chaffy grains per panicle were determined by counting the grains in ten panicles of randomly selected plants and mean was calculated.

3.3.2.3 Test weight (1000-seed weight)

From the seed yield of each net plot, 1000 seeds were randomly counted and weight was recorded and expressed in grams.

3.3.2.4 Grain yield (kg ha⁻¹)

The crop in the net plot was harvested, threshed, dried in the sun. The grains were cleaned and weight was recorded and converted into kg per hectare.

3.3.2.5 Straw yield (kg ha⁻¹)

The straw from the net plot after threshing was dried in the sun, weighed and converted into kg per hectare.

3.3.2.6 Harvest index

Harvest index was calculated by the formula as outlined by Donald (1962).

$$\text{Harvest index} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Grain yield (kg ha}^{-1}\text{)} + \text{Straw yield (kg ha}^{-1}\text{)}}$$

3.4 Collection of soil and plant samples

Plant samples were collected before split application of K₂O and at harvest and analyzed for nutrient content. Soil samples were collected at harvest and analyzed for various nutrient content.

3.5 Plant analysis

Plant samples collected at various stages and seed samples at harvest were processed in the laboratory, dried and powdered. The powdered plant and seed samples were pre-digested with HNO₃ for a period of twelve hours then treated with di-acid (HNO₃:HClO₄ in 10:4 ratio) mixture and digested on sand bath till a snow white residue was obtained. It was cooled and the volume was made up to 100 ml using 6 N HCl (Piper, 1966).

3.5.1 Total potassium

Using the respective di-acid digests of Plant and seed, the total potassium content of the above materials was estimated by atomizing the diluted digest to a



ICAR Research Project on
*Effect of potassium & its split application
on growth, yield and uptake by paddy*
Replicates : 4 Treatments : 10
Variety : BG-4
Date of Sowing : 01.06.2017
Date of Harvesting : 14.06.2017

R₁T₄

Plate 1: General view of field experiment

calibrated flame photometer under suitable measuring conditions prescribed by Jackson (1973).

3.5.2 Total calcium and magnesium

Calcium and magnesium contents in Plant and seed were determined by taking a known volume of respective digest and following the EDTA titration method for estimation (Jackson, 1973).

3.5.3 Uptake of potassium, calcium and magnesium by grain and straw of paddy

The uptake of nutrient by grain and straw of paddy was worked out by multiplying the dry matter yield of grain and straw with their nutrients content as given in the following formula:

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content (\%)} \times \text{Dry matter yield (kg ha}^{-1}\text{)}}{100}$$

3.6 Potassium use efficiency

The potassium use efficiency was worked out as given in the following formula

$$\text{Potassium use efficiency (\%)} = \frac{\text{Yield potassium treat plot} - \text{yield of control plot}}{\text{Quantity of potassium applied to treated plot}} \times 100$$

3.7 Soil analysis

The composite samples were collected from each plot at the time of harvest, air dried under shade, ground gently using wooden pestle and mortar and passed through 2 mm sized sieve for further analysis. For organic carbon analysis, the samples were subjected to further grinding and passed through 0.2mm sieve.

3.7.1 Soil pH

The pH of soils was determined in 1:2.5 soil water suspension, potentiometrically using pH meter (Jackson, 1973).

3.7.2 Electrical conductivity

Electrical conductivity was determined in the clear liquid of the soil water suspension (1:2) with the help of conductivity meter (Jackson, 1973).

3.7.3 Organic carbon

Organic carbon was estimated by Walkley and Black's wet oxidation method as described by Jackson (1973). In this method, the soil was oxidized using a known

excess of 1 N potassium dichromate solution in the presence of concentrated H₂SO₄. The excess K₂Cr₂O₇ not reduced by organic matter of soil was determined by titration with standard ferrous ammonium sulfate solution in the presence of diphenylamine indicator.

3.7.4 Available nitrogen

The available nitrogen in the soil was determined by alkaline potassium permanganate distillation method as described by Subbiah and Asija, (1959).

3.7.5 Available phosphorus

Available phosphorus in the soil samples was extracted using Bray's extractant (Jackson, 1973) and estimated colorimetrically by using a spectrophotometer.

3.7.6 Available potassium

Available potassium in the soil samples was extracted using neutral normal ammonium acetate and potassium content in the extract was estimated using a flame photometer (Jackson, 1973).

3.7.7 Exchangeable calcium and magnesium

The exchangeable calcium and magnesium contents were determined by extracting the soils with neutral normal ammonium acetate solution an aliquot of the extract was used to estimate calcium and magnesium by EDTA titration (Jackson, 1973).

3.7.8 Available sulfur

Available sulfur was extracted from the soil using 0.15 per cent calcium chloride solution and sulfur in solution was determined by turbidometry as outlined by Black (1965) using Spectrophotometer at 420 nm.

3.8 Forms of potassium

Potassium in soil was fractionated into different forms such as water-soluble (WS-K), exchangeable (Exch-K) and non-exchangeable (Non-exch-K), Lattice-K found to be the dominant fraction in soils. These fractions are fractionated by a procedure as described by Pratt (1982) using flame photometry.

3.8.1 Water-soluble potassium

Five grams soil was taken into a 50 ml capacity centrifuge tube and 25 ml of distilled water was added. The contents were shaken for one hour, centrifuged,

filtered and collected the filtrate. The concentration of the water-soluble potassium present in the filtrate was determined by flame photometry (Jackson, 1973).

3.8.2 Exchangeable potassium

Five grams soil was taken into 50 ml centrifuge tube containing 25ml of neutral N ammonium acetate. After shaking for 5 minutes, the contents were filtered and the filtrate was collected. The potassium in the filtrate was estimated using flame photometry (Jackson, 1973) and expressed as available K. exchangeable potassium was calculated by subtracting the water-soluble K from ammonium acetate extractable K.

$$\text{Exchangeable K} = [\text{Available K} - \text{Water soluble K}]$$

3.8.3 Non-exchangeable (fixed) potassium

Two and half-gram of soil were taken into a 250 ml beaker, to which 25 ml of 1 N HNO₃ was added. The contents were boiled on a hot plate for 10 minutes, cooled and filtered. The filtrate was collected in a 50 ml volumetric flask. The residue on the filter paper was washed with four portions of 5ml of 0.1 N HNO₃. After making up the volume, the total potassium in the extract was determined by flame photometry (Wood and De Turk, 1940) and expressed as HNO₃ extractable K. Finally, the fixed K or non-exchangeable K was calculated by subtracting the available K in the HNO₃ extractable K.

$$\text{Non exchangeable K} = [\text{HNO}_3 \text{ extractable K} - \text{Available K}]$$

3.8.4 Lattice potassium

Lattice potassium of the soil was obtained by subtracting the sum of the water-soluble, exchangeable and non-exchangeable K fractions in total potassium of the soil *i.e.*,

$$\text{Lattice K} = \text{Total K} - \sum (\text{water-soluble K} + \text{Exch. K} + \text{Non.exch. K})$$

3.8.5 HF digestion for total potassium analysis

Total potassium in soils was determined by digesting the samples with hydrofluoric acid in closed vessel (Sridhar and Jackson, 1974) for this finely powdered and oven dried soil sample of 0.2g was taken in polypropylene bottle, to this 2ml Auarigia (HNO₃ + HCl) was added to decompose the carbonates and disperse the sample. Then 20ml HF was added and shaken for 10 hours after capping the bottle immediately. Finally, 50ml saturated solution of boric acid was added and shaken for 2 hours to dissolve the sample completely. Finally, the volume

was made up to 100ml (Jackson, 1973). The digest thus obtained was used for total elemental analysis.

3.9 Statistical analysis

The experimental data obtained were subjected to statistical analysis by adopting Fisher's method of analysis of variance as outlined by Gomez and Gomez (1984). The level of significance used in F test was at 5 per cent. Critical difference (CD) values are given for the data at 5 per cent level of significance, wherever the F test was significant. The relationship between yield parameters, content K in grain and straw, grain and straw yield, fractions of potassium was worked out using simple correlation.

Experimental Results

IV EXPERIMENTAL RESULTS

The results of the field experiment entitled “Effect of levels and split application of potassium on the productivity of paddy and status of potassium in alluvial soil of coastal region of Karnataka” conducted during *kharif* 2017 at Zonal Agricultural and Horticultural Research Station (ZAHRS), Brahmavar, UAHS, Shivamogga are presented in this chapter.

4.1 Experimental results on growth parameters

The data on growth components such as plant height and number of tillers per m² as influenced by different levels and split application of potassium are presented in Table 2.

4.1.1 Plant height (cm)

The data pertaining to plant height of rice at different growth stages as influenced by levels and split application of potassium at 60 days after transplanting (DAT) and at harvest are presented in Table 2. At 60 days after transplanting (DAT) plant height differed significantly. The higher plant height (83.32 cm) was recorded with application of 75 kg potassium in three equal split applications which was on par with 75 kg potassium applied in two equal splits (82.36 cm). Lower plant height was recorded in no potassium application (71.24 cm). And at harvest significantly highest plant height (115.56 cm) was recorded with application of 75 kg potassium in three equal split applications. 60 kg potassium at basal, three equal splits and potassium with 75 kg at basal and two equal split showed on par among them. Lower plant height was recorded in no potash application (91.99 cm).

4.1.2 Number of tillers per m²

Data pertaining to number of tillers per m² of rice as influenced by levels and split application of potassium at 60 days after transplanting (DAT) and at harvest are presented in Table 2. At 60 DAT the higher number of tillers per m² (443.75) was observed with application of 75 kg potassium in three equal split application which was on par with two equal split application of 75 kg potassium (427.25) which were significantly higher over other treatments. Lower number of tillers per m² (308.00) was recorded with no potassium application. At harvest, significantly higher number of tillers per m² (482.25) was observed with application of 75 kg potassium in three equal split applications followed by 75 kg potassium application in two equal splits (452.27). Significantly lower number of tillers per m² (369.75) was recorded where no potassium was applied.

Table 2 : Effect of potassium levels and its split application on growth and yield parameters of paddy.

TREATMENTS	Plant height (cm)		Number of tillers m ⁻²		Panicle length (cm)	Test weight (g)	Filled grains per panicle	Chaffy grains per panicle
	60 DAT	Harvest	60 DAT	Harvest				
	T ₁ : 45 kg K ₂ O ha ⁻¹ at basal	75.13	106.42	335.00				
T ₂ : 60 kg K ₂ O ha ⁻¹ at basal	77.51	109.67	364.75	422.50	21.62	22.86	93.85	14.85
T ₃ : 75 kg K ₂ O ha ⁻¹ at basal	79.87	110.62	370.00	435.00	22.71	23.60	97.68	13.68
T ₄ : 45 kg K ₂ O ha ⁻¹ in two equal splits	75.72	107.10	349.25	412.75	21.35	23.41	91.50	16.55
T ₅ : 60 kg K ₂ O ha ⁻¹ in two equal splits	77.81	109.32	365.25	427.00	21.76	23.39	95.50	14.28
T ₆ : 75 kg K ₂ O ha ⁻¹ in two equal splits	82.36	110.69	427.25	452.75	22.81	24.90	101.30	13.20
T ₇ : 45 kg K ₂ O ha ⁻¹ in three equal splits	75.72	108.57	359.25	421.75	21.61	23.73	92.50	16.30
T ₈ : 60 kg K ₂ O ha ⁻¹ in three equal splits	78.82	110.60	366.75	430.25	22.39	23.82	97.45	13.78
T ₉ : 75 kg K ₂ O ha ⁻¹ in three equal splits	83.32	115.05	443.75	482.25	23.05	25.34	108.98	11.00
T ₁₀ : No K is applied	71.24	91.99	308.00	369.75	20.92	19.97	79.25	24.68
S.Em. ±	2.28	3.17	10.37	15.71	0.47	0.691	3.14	1.33
C.D. at 5%	6.66	9.22	31.63	45.18	1.28	1.98	9.13	3.85

Two equal splits- first at time of transplanting and second at 55- 60 DAT

Three equal splits- first at time of transplanting, second at 25- 30 DAT and third at 55-60 DAT

DAT: Days after transplanting

4.1.3 Panicle length (cm)

Among different levels and splits of potassium, significantly higher panicle length (23.05 cm) was observed with application of 75 kg potassium in three equal split application which was followed with application of 75 kg potassium in two equal split application (22.81 cm). Whereas, significantly lower panicle length (20.92 cm) was observed with no potassium application (Table 2).

4.1.4 Test weight (1000 seeds) of paddy

Among different levels and splits of potassium, significantly higher test weight of paddy seeds (25.34 g) was recorded in with application of 75 kg potassium in three equal splits, which was followed by two equal split application of 75 kg potassium (24.89 g). Whereas, significantly lower test weight of paddy seeds (19.97 g) was recorded in no potassium application (Table 2).

4.1.5 Number of filled grains per panicle

Significantly higher number of filled grains per panicle was observed with application of different levels and splits of potassium (Table 2). Among different levels and splits of potassium, significantly more number of filled grains per panicle (108.97) was observed with application of 75 kg potassium in three equal splits, and it was significant over all treatments. Lower number of filled grains per panicle (79.25) was observed in no potassium application.

4.1.6 Chaffy grains per panicle

Among different levels and splits of potassium, significantly higher number of chaffy grains per panicle (24.67) was recorded in no potassium application, which was significant over all the treatments. Whereas, significantly lower number of chaffy grains per panicle (11.00) was recorded with application of 75 kg potassium in three equal splits (Table 2).

4.2 Yield of paddy

The grain yield, straw yield and harvest index as influenced by different levels and split application of potassium are presented in Table 3.

4.2.1 Grain yield (kg ha⁻¹)

Data pertaining to grain and straw yield and harvest index of paddy under, different levels and split application of potassium are presented in Table 3. Grain yield of rice under levels and split application of potassium was influenced greatly. Significantly higher grain yield (7733 kg ha⁻¹) was observed with application of

Table 3 : Effect of potassium levels and its split application on grain & straw yield and harvest index of paddy.

TREATMENTS	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Harvest index (%)
T ₁ : 45 kg K ₂ O ha ⁻¹ at basal	5531	6194	0.472
T ₂ : 60 kg K ₂ O ha ⁻¹ at basal	6222	7031	0.469
T ₃ : 75 kg K ₂ O ha ⁻¹ at basal	6939	7910	0.468
T ₄ : 45 kg K ₂ O ha ⁻¹ in two equal splits	5718	6404	0.472
T ₅ : 60 kg K ₂ O ha ⁻¹ in two equal splits	6525	7373	0.469
T ₆ : 75 kg K ₂ O ha ⁻¹ in two equal splits	7332	8358	0.468
T ₇ : 45 kg K ₂ O ha ⁻¹ in three equal splits	5917	6627	0.470
T ₈ : 60 kg K ₂ O ha ⁻¹ in three equal splits	6898	7693	0.472
T ₉ : 75 kg K ₂ O ha ⁻¹ in three equal splits	7733	8815	0.467
T ₁₀ : No K is applied	5185	5963	0.465
S.E.m. ±	203.41	238.58	0.007
C.D. at 5%	583.79	692.09	NS

Two equal splits- first at time of transplanting and second at 55- 60 DAT

Three equal splits- first at time of transplanting, second at 25- 30 DAT and third at 55-60 DAT

NS: Non significant

DAT: Days after transplanting

75 kg potassium in three equal splits, followed by application of 75 kg potassium in two equal splits (7332 kg ha^{-1}) which was on par among them. Whereas, significantly lower grain yield (5185 kg ha^{-1}) was observed in no potassium application.

4.2.2 Straw yield (kg ha^{-1})

The trend of straw yield followed similar pattern as that of grain yield. Significantly higher straw yield was produced by the application of different levels and splits of potassium. Among different levels and splits, significantly higher straw yield (8815 kg ha^{-1}) was recorded with application of 75 kg potassium in three equal splits, which was followed by application of 75 kg potassium in two equal splits (8357 kg ha^{-1}). Whereas, lower straw yield (5963 kg ha^{-1}) was recorded in no potassium application.

4.2.3 Harvest index (HI)

Harvest index of paddy under different levels and splits of potassium did not differ significantly among the different treatments. However, higher harvest index (0.472) was recorded with application of 60 kg potassium in three equal splits and 45 kg potassium in two equal splits. Lower harvest index (0.465) was noticed in no potassium application.

4.3 Nutrient concentration in paddy at different growth stages

The data pertaining to the nutrient content *viz.*, potassium, calcium and magnesium content in the plant as influenced by different levels and split application of potassium at different growth stages of paddy are presented in Table 4.

4.3.1 Effect of potassium levels and its split application on potassium content at 30 DAT, 60 DAT and at harvest of paddy

The data pertaining to the potassium content in the plant as influenced by different levels and split application of potassium are presented in Table 4. There was significant variation in potassium content of the plant due to application of different levels and splits of potassium at 30 DAT, 60 DAT, and at harvest.

At 30 DAT significantly highest total potassium content (2.55 per cent and 2.42 per cent) was recorded in treatment with 75 kg potassium application in three equal splits followed with 75 kg potassium application in two equal splits, respectively. Lower potassium content (1.77 per cent) was recorded in no potassium application.

Table 4 : Effect of potassium levels and its split application on nutrient content (%) of paddy at 30 DAT, 60 DAT and at harvest

TREATMENTS	Potassium (%)		Calcium (%)		Magnesium (%)	
	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT
T ₁ : 45 kg K ₂ O ha ⁻¹ at basal	1.79	1.50	0.41	0.39	0.10	0.09
T ₂ : 60 kg K ₂ O ha ⁻¹ at basal	2.03	1.87	0.45	0.28	0.08	0.10
T ₃ : 75 kg K ₂ O ha ⁻¹ at basal	2.22	2.56	0.34	0.32	0.09	0.09
T ₄ : 45 kg K ₂ O ha ⁻¹ in two equal splits	1.91	1.76	0.55	0.38	0.09	0.11
T ₅ : 60 kg K ₂ O ha ⁻¹ in two equal splits	2.09	1.93	0.42	0.40	0.08	0.10
T ₆ : 75 kg K ₂ O ha ⁻¹ in two equal splits	2.42	2.63	0.47	0.17	0.09	0.09
T ₇ : 45 kg K ₂ O ha ⁻¹ in three equal splits	1.99	1.80	0.56	0.44	0.10	0.10
T ₈ : 60 kg K ₂ O ha ⁻¹ in three equal splits	2.21	2.27	0.52	0.43	0.07	0.10
T ₉ : 75 kg K ₂ O ha ⁻¹ in three equal splits	2.56	2.78	0.49	0.30	0.07	0.11
T ₁₀ : No K is applied	1.77	1.44	0.60	0.57	0.10	0.07
S.E.m. ±	0.30	0.30	0.06	0.07	0.012	0.012
C.D. at 5%	0.89	0.89	NS	NS	NS	NS

Two equal splits- first at time of transplanting and second at 55- 60 DAT

Three equal splits- first at time of transplanting, second at 25- 30 DAT and third at 55-60 DAT

NS: Non significant

DAT: Days after transplanting



T₁: 45 kg potassium application as basal



T₂: 60 kg potassium application as basal



T₃: 75 kg potassium application as basal



T₄: 45 kg potassium application in two equal splits

Plate 2a: Comparison of different treatments at the time of harvest



T₅: 60 kg potassium application in two equal splits



T₆: 75 kg potassium application in two equal splits



T₇: 45 kg potassium application in three equal splits



T₈: 60 kg potassium application in three equal splits

Plate 2b: Comparison of different treatments at the time of harvest



T₉: 75 kg potassium application in three equal splits



T₁₀: no potassium application

Plate 2c: Comparison of different treatments at the time of harvest

At 90 DAT and at harvest, significantly higher potassium content (2.78 per cent and 1.97 per cent, respectively) was recorded in treatment receiving, 75 kg potassium application in three equal splits closely followed by application of 75 kg potassium in two equal splits (2.63 per cent and 1.89 per cent, respectively). Lower potassium content (1.44 per cent and 1.28 per cent, respectively) was recorded in no potassium applied treatment.

4.3.2 Effect of potassium levels and its split application on calcium and magnesium content at 30 DAT, 60 DAT and at harvest of paddy

The data pertaining to the total nutrient content of calcium and magnesium in paddy under different levels and split application of potassium are presented in Table 4. There was no significant variation in calcium content of the plant due to the application of different treatments at 30 DAT, 60 DAT and at harvest.

At 30 DAT, 60 DAT and at harvest calcium content ranged from 0.34 to 0.6, 0.17 to 0.57 and 0.45 to 0.73 per cent, respectively and magnesium content ranged from 0.07 to 0.1, 0.07 to 0.11 and 0.14 to 0.19 per cent, respectively.

4.3.3 Effect of potassium levels and its split application on potassium, calcium and magnesium content in straw and grain of paddy at harvest.

The data pertaining to the potassium, calcium and magnesium content in the straw and grain as influenced by different levels and split application of potassium are presented in Table 5. There was significant variation in potassium content of paddy straw and grain due to application of different levels and splits of potassium at harvest. No significant difference was observed in calcium and magnesium content in straw and grain.

At harvest in paddy straw significantly highest total potassium content (1.55 per cent) was recorded in treatment with 75 kg potassium application in three equal splits followed with 75 kg potassium application in two equal splits (1.47 per cent), respectively. Lower potassium content in straw (0.96 per cent) was recorded in no potassium applied treatment.

Significantly highest potassium content in grain (0.43 per cent) was recorded in treatment with 75 kg potassium application in three equal splits on par with 75 kg potassium application in two equal splits (0.42 per cent) and basal application (0.42 per cent). Lower potassium content (0.31 per cent) was recorded in no potassium application.

At harvest calcium content in straw and grain ranged between 0.32 to 0.61, 0.12 to 0.17 per cent, respectively and magnesium content in straw and grain ranged between 0.07 to 0.1, 0.05 to 0.1 per cent, respectively.

Table 5 : Effect of potassium levels and its split application on nutrient content (%) of potassium, calcium and magnesium in straw and grain of paddy after the harvest

TREATMENTS	Potassium		Calcium		Magnesium	
	Straw	Grain	Straw	Grain	Straw	Grain
T ₁ : 45 kg K ₂ O ha ⁻¹ at basal	1.11	0.36	0.61	0.12	0.08	0.07
T ₂ : 60 kg K ₂ O ha ⁻¹ at basal	1.17	0.38	0.48	0.14	0.08	0.08
T ₃ : 75 kg K ₂ O ha ⁻¹ at basal	1.32	0.42	0.48	0.13	0.07	0.08
T ₄ : 45 kg K ₂ O ha ⁻¹ in two equal splits	1.14	0.37	0.37	0.17	0.08	0.10
T ₅ : 60 kg K ₂ O ha ⁻¹ in two equal splits	1.34	0.39	0.33	0.15	0.09	0.09
T ₆ : 75 kg K ₂ O ha ⁻¹ in two equal splits	1.47	0.42	0.38	0.16	0.08	0.09
T ₇ : 45 kg K ₂ O ha ⁻¹ in three equal splits	1.18	0.39	0.43	0.15	0.09	0.09
T ₈ : 60 kg K ₂ O ha ⁻¹ in three equal splits	1.36	0.41	0.38	0.12	0.09	0.07
T ₉ : 75 kg K ₂ O ha ⁻¹ in three equal splits	1.55	0.43	0.32	0.17	0.08	0.10
T ₁₀ : No K is applied	0.96	0.32	0.37	0.08	0.10	0.05
S.Em. ±	0.04	0.02	0.06	0.028	0.009	0.017
C.D. at 5%	0.13	0.045	NS	NS	NS	NS

Two equal splits- first at time of transplanting and second at 55- 60 DAT

Three equal splits- first at time of transplanting, second at 25- 30 DAT and third at 55-60 DAT

NS: Non significant

DAT: Days after transplanting

4.4 Nutrient uptake by paddy crop

4.4.1 Potassium uptake (kg ha^{-1})

Data pertaining to the uptake of potassium by paddy grain and straw under different levels and split application of potassium are presented in Table 6.

Significant differences existed in the potassium uptake by grain, straw. Significantly higher potassium uptake in straw ($135.93 \text{ kg ha}^{-1}$) was recorded in plots applied with 75 kg potassium in three equal splits followed by 75 kg potassium application in two equal splits ($122.78 \text{ kg ha}^{-1}$). Whereas significantly lower potassium uptake in straw was recorded in no potassium application (57.40 kg ha^{-1}).

Significant potassium uptake by grain (32.86 kg ha^{-1}) was recorded in treatment receiving 75 kg potassium in three equal splits followed by 75 kg potassium in two splits and as basal application. Lower potassium content in grain (16.35 kg ha^{-1}) was noticed in plots treated with no potassium application *i.e.*, in control plot.

4.4.1 Calcium and magnesium uptake (kg ha^{-1})

Data pertaining to uptake of calcium and magnesium by paddy grain and straw as influenced by different levels and split application of potassium are presented in Table 6.

Uptake of calcium and magnesium by straw and grain of paddy did not vary significantly. Calcium uptake in straw and grain ranged from 22.35 kg ha^{-1} to 37.89 kg ha^{-1} and 4.06 kg ha^{-1} to 13.02 kg ha^{-1} respectively. Similarly magnesium uptake in straw and grain ranged from 4.84 kg ha^{-1} to 7.41 kg ha^{-1} and 2.44 kg ha^{-1} to 7.81 kg ha^{-1} , respectively.

4.5 Chemical properties and available nutrient status in soil after the harvest of the crop

The data pertaining to chemical properties of soil at harvest as influenced by different levels and split application of potassium are presented in Table 7 and Table 8.

4.5.1 Soil pH

The soil pH of soil after the harvest of paddy was not influenced significantly due to different levels and split application of potassium. However, its value in the experimental plots ranged from 5.23 to 5.45.

Table 6 : Effect of potassium levels and its split application on nutrient uptake (kg ha⁻¹) by paddy

TREATMENTS	Potassium		Calcium		Magnesium	
	Straw	Grain	Straw	Grain	Straw	Grain
T1: 45 kg K ₂ O ha ⁻¹ at basal	68.90	19.78	37.89	6.69	4.84	4.01
T2: 60 kg K ₂ O ha ⁻¹ at basal	82.09	23.79	33.44	8.58	5.43	5.14
T3: 75 kg K ₂ O ha ⁻¹ at basal	104.35	29.13	37.72	8.85	5.57	5.31
T4: 45 kg K ₂ O ha ⁻¹ in two equal splits	72.78	21.14	23.75	9.67	5.43	5.80
T5: 60 kg K ₂ O ha ⁻¹ in two equal splits	98.47	25.27	24.16	9.91	6.34	5.94
T6: 75 kg K ₂ O ha ⁻¹ in two equal splits	122.78	30.61	31.02	11.53	6.63	6.91
T7: 45 kg K ₂ O ha ⁻¹ in three equal splits	77.87	22.81	28.44	8.88	5.91	5.32
T8: 60 kg K ₂ O ha ⁻¹ in three equal splits	104.17	28.17	29.45	8.65	6.63	5.19
T9: 75 kg K ₂ O ha ⁻¹ in three equal splits	135.93	32.86	27.09	13.02	7.41	7.81
T ₁₀ : No K is applied	57.40	16.35	22.35	4.06	5.73	2.44
S.Em. ±	4.238	1.285	4.01	1.96	0.77	1.18
C.D. at 5%	12.36	3.74	NS	NS	NS	NS

Two equal splits- first at time of transplanting and second at 55- 60 DAT

Three equal splits- first at time of transplanting, second at 25- 30 DAT and third at 55-60 DAT

NS: Non significant

DAT: Days after transplanting

Table 7 : Effect of potassium levels and its split application on pH, EC(d Sm⁻¹) and organic carbon (g kg⁻¹) in soil after the harvest of paddy

TREATMENTS	pH	EC (d Sm ⁻¹)	Organic carbon (g kg ⁻¹)
T1: 45 kg K ₂ O ha ⁻¹ at basal	5.32	0.023	10.0
T2: 60 kg K ₂ O ha ⁻¹ at basal	5.45	0.028	11.9
T3: 75 kg K ₂ O ha ⁻¹ at basal	5.24	0.027	12.6
T4: 45 kg K ₂ O ha ⁻¹ in two equal splits	5.45	0.029	11.2
T5: 60 kg K ₂ O ha ⁻¹ in two equal splits	5.40	0.026	11.5
T6: 75 kg K ₂ O ha ⁻¹ in two equal splits	5.29	0.027	10.9
T7: 45 kg K ₂ O ha ⁻¹ in three equal splits	5.29	0.025	11.4
T8: 60 kg K ₂ O ha ⁻¹ in three equal splits	5.23	0.028	11.9
T9: 75 kg K ₂ O ha ⁻¹ in three equal splits	5.39	0.029	11.8
T10: No K is applied	5.43	0.026	10.0
S.E.m. ±	0.127	0.005	0.68
C.D. at 5%	NS	NS	NS

Two equal splits- first at time of transplanting and second at 55- 60 DAT

Three equal splits- first at time of transplanting, second at 25- 30 DAT and third at 55-60 DAT

NS: Non significant

DAT: Days after transplanting

Table 8 : Effect of potassium levels and its split application on primary and secondary nutrients in soil after the harvest of paddy.

TREATMENTS	Avail. N (kg ha ⁻¹)	Avail. P ₂ O ₅ (kg ha ⁻¹)	Avail. K ₂ O (kg ha ⁻¹)	Sulphur (mg kg ⁻¹)	Calcium (cmol(P ⁺)kg ⁻¹)	Magnesium (cmol(P ⁺)kg ⁻¹)
T ₁ : 45 kg K ₂ O ha ⁻¹ at basal	537	38	101.01	26.72	1.11	0.70
T ₂ : 60 kg K ₂ O ha ⁻¹ at basal	533	47	102.75	30.43	0.74	0.93
T ₃ : 75 kg K ₂ O ha ⁻¹ at basal	574	38	104.26	22.25	0.78	1.81
T ₄ : 45 kg K ₂ O ha ⁻¹ in two equal splits	579	36	101.28	23.17	1.14	1.42
T ₅ : 60 kg K ₂ O ha ⁻¹ in two equal splits	541	37	94.98	33.31	1.18	1.23
T ₆ : 75 kg K ₂ O ha ⁻¹ in two equal splits	620	36	104.38	22.54	0.83	1.21
T ₇ : 45 kg K ₂ O ha ⁻¹ in three equal splits	561	38	98.09	22.73	0.78	1.10
T ₈ : 60 kg K ₂ O ha ⁻¹ in three equal splits	596	37	98.43	27.24	0.82	1.24
T ₉ : 75 kg K ₂ O ha ⁻¹ in three equal splits	655	43	91.32	25.91	1.13	0.94
T ₁₀ : No K is applied	603	36	78.14	25.60	0.78	1.07
S.Em. ±	28.04	6.53	4.95	3.44	0.25	0.23
C.D. at 5%	NS	NS	14.44	NS	NS	NS

Two equal splits- first at time of transplanting and second at 55- 60 DAT

Three equal splits- first at time of transplanting, second at 25- 30 DAT and third at 55-60 DAT

NS: Non significant

DAT: Days after transplanting

4.5.2 Electrical conductivity

No considerable change concerning electrical conductivity was noticed due to the application of potassium according to treatments. However, electrical conductivity in experimental plots ranged from 0.023 to 0.029 dS m⁻¹.

4.5.3 Organic carbon

Organic carbon did not show significant difference due to different levels and split application of potassium. However, organic carbon content in experimental plots ranged from 10.00 to 12.60 g kg⁻¹.

4.5.4 Available nitrogen

Available nitrogen in experimental plots did not differ significantly due to different levels and split application of potassium, available nitrogen in plots ranged from 533 kg ha⁻¹ to 655.10 kg ha⁻¹.

4.5.5 Available phosphorus

Phosphorus status in soil did not differ significantly due to different levels and split application of potassium. However phosphorous ranged between 36.22 kg ha⁻¹ to 47.02 kg ha⁻¹.

4.5.6 Available potassium

Potassium availability in the soil after harvest of paddy under different levels and split application of potassium varied significantly. Higher available soil potassium (104.38 kg ha⁻¹) was observed with application of 75 kg of potassium in two equal split application and it was followed by other treatments. Whereas, significantly lower available soil potassium (78.14 kg ha⁻¹) was recorded in no potassium application.

4.5.7 Exchangeable calcium

Calcium in the soil after harvest of paddy under different levels and split application of potassium did not differ significantly. However exchangeable calcium content of experimental plots varied from 0.74 cmol(P⁺) kg⁻¹ to 1.18 cmol(P⁺) kg⁻¹.

4.5.8 Exchangeable magnesium

Magnesium in soil after harvest of paddy under different levels and split application of potassium did not varied significantly. However exchangeable magnesium content of experimental plots varied from 0.70 cmol (P⁺) kg⁻¹ to 1.81 cmol (p⁺) kg⁻¹.

4.5.9 Available sulphur

Sulphur in the soil after harvest of rice under different levels and split application of potassium did not differ significantly. Available sulphur content in soil ranged from 22.25 to 33.31 mg kg⁻¹.

4.6 Forms and distribution of potassium in soil after harvest of paddy

Data presented in Table 9 indicate the distribution of different potassium fractions in soil after harvest of paddy as influenced by different levels and split application of potassium.

Results indicate that water soluble potassium in the soil after harvest of crop differed significantly due to different levels and split application of potassium. Significantly higher water soluble potassium was recorded with application of 75 kg potassium in three equal splits (23.61 mg kg⁻¹) and was on par with 45 kg potassium application in three equal splits (23.39 mg kg⁻¹), 45 kg potassium application at basal (23.28 mg kg⁻¹). Lowest water soluble potassium was recorded in 75 kg potassium application in two equal splits applied plots (20.10 mg kg⁻¹).

Significantly higher exchangeable potassium was observed with application of 75 kg potassium in two equal splits (38.83 mg kg⁻¹) which was on par with all the treatments except no potassium applied. Lower exchangeable soluble potassium was recorded in no potassium applied plots (29.07 mg kg⁻¹).

Significantly higher non-exchangeable potassium was seen with the application of 60 kg potassium in three equal splits (264.90 mg kg⁻¹) and followed by 75 kg potassium application at three equal splits (245.82 mg kg⁻¹) and two equal splits (247.91 mg kg⁻¹). Lower non-exchangeable potassium recorded in no potassium application (137.40 mg kg⁻¹).

Significantly higher lattice potassium was recorded with application of 45 kg potassium in two equal splits (1504.15 mg kg⁻¹) and followed by 60 kg potassium application in two equal splits (1410.09 mg kg⁻¹) and 60 kg potassium application as basal (1357.18 mg kg⁻¹). Lower lattice potassium was recorded with no potassium application (1199.93 mg kg⁻¹).

Significantly higher total potassium was observed with application of 45 kg potassium in two equal splits (1744 mg kg⁻¹) which was on par with 60 kg potassium application in two equal splits (1668 mg kg⁻¹), at basal (1596 mg kg⁻¹), at three equal splits (1541 mg kg⁻¹) and 75 kg potassium with three equal splits (1614 mg kg⁻¹). Lower total potassium recorded with no potassium application (1390 mg kg⁻¹).

Table 9 : Effect of potassium levels and its split application on potassium forms (mg kg⁻¹) after the harvest of paddy

TREATMENTS	Water soluble K	Exch. K	Non-exch. K	Lattice K	Total K
T1: 45 kg K ₂ O ha ⁻¹ at basal	23.28 (1.61)	37.58 (2.61)	163.53 (11.34)	1218.01 (84.44)	1442
T2: 60 kg K ₂ O ha ⁻¹ at basal	21.61 (1.34)	38.23 (2.39)	179.50 (11.24)	1357.18 (85.02)	1596
T3: 75 kg K ₂ O ha ⁻¹ at basal	23.39 (1.38)	38.79 (2.53)	165.16 (10.76)	1309.32 (85.33)	1534
T4: 45 kg K ₂ O ha ⁻¹ in two equal splits	20.42 (1.24)	37.68 (2.16)	180.72 (10.36)	1504.15 (86.24)	1744
T5: 60 kg K ₂ O ha ⁻¹ in two equal splits	21.90 (1.31)	35.34 (2.12)	200.29 (12.01)	1410.09 (84.56)	1668
T6: 75 kg K ₂ O ha ⁻¹ in two equal splits	20.10 (1.35)	38.83 (2.54)	247.91 (16.24)	1218.70 (79.86)	1526
T7: 45 kg K ₂ O ha ⁻¹ in three equal splits	21.13 (1.59)	36.49 (2.49)	156.35 (10.66)	1250.77 (85.26)	1467
T8: 60 kg K ₂ O ha ⁻¹ in three equal splits	20.66 (1.30)	36.62 (2.38)	264.91 (17.19)	1219.62 (79.13)	1541
T9: 75 kg K ₂ O ha ⁻¹ in three equal splits	23.61 (1.46)	33.97 (2.11)	245.82 (15.23)	1310.34 (81.20)	1614
T10: No K is applied	23.30 (1.68)	29.07 (2.09)	137.40 (9.89)	1199.93 (86.34)	1390
S.Em. ±	0.782	1.938	23.60	64.36	70.40
C.D. at 5%	2.28	5.65	68.84	187.75	205.37

Two equal splits- first at time of transplanting and second at 55- 60 DAT

Three equal splits- first at time of transplanting, second at 25- 30 DAT and third at 55-60 DAT

NS: Non significant

DAT: Days after transplanting

Note: Parenthesis indicate the percentage of potassium fractions

4.7 Potassium use efficiency by paddy.

Due to different potassium levels and its split application, potassium use efficiency vary greatly (Table 10). Highest potassium use efficiency was recorded (33.96 %) with 75 kg potassium application in three equal splits and lowest was recorded (7.67 %) with application of 45 kg potassium as basal dose.

4.8 Relationship between potassium fractions of soil and content of K in grain and straw yield of paddy

Simple correlation co-efficient (r) values observed between the yield parameter and content of K in grain and straw of paddy and different forms of potassium in soil are presented in Table 11.

The exchangeable potassium was positively and significantly correlated with grain yield ($r = 0.315^*$), straw yield ($r = 0.277^*$), K content in grains ($r = 0.544^*$), the content of K in straw ($r = 0.322^*$).

There was a significant correlation between water soluble K and exchangeable K ($r = 0.599^*$), non-exchangeable K ($r = 0.499^*$), straw yield ($r = 0.351$). Non-exchangeable K significantly correlated with content of K in grain ($r = 0.719$), K content in straw ($r = 0.840^{**}$), grain yield ($r = 0.809^{**}$) and straw yield ($r = 0.783^{**}$).

Table 10 : Effect of levels and split application of potassium on potassium use efficiency (%) in paddy

TREATMENTS	Potassium use efficiency (%)
T ₁ : 45 kg K ₂ O ha ⁻¹ at basal	7.67
T ₂ : 60 kg K ₂ O ha ⁻¹ at basal	17.28
T ₃ : 75 kg K ₂ O ha ⁻¹ at basal	23.38
T ₄ : 45 kg K ₂ O ha ⁻¹ in two equal splits	11.83
T ₅ : 60 kg K ₂ O ha ⁻¹ in two equal splits	22.33
T ₆ : 75 kg K ₂ O ha ⁻¹ in two equal splits	28.62
T ₇ : 45 kg K ₂ O ha ⁻¹ in three equal splits	16.27
T ₈ : 60 kg K ₂ O ha ⁻¹ in three equal splits	28.55
T ₉ : 75 kg K ₂ O ha ⁻¹ in three equal splits	33.96
T ₁₀ : No K is applied	

Two equal splits- first at time of transplanting and second at 55- 60 DAT

Three equal splits- first at time of transplanting, second at 25- 30 DAT and third at 55-60 DAT

Table 11 : Correlation among potassium forms with yield parameter, K content in grain and straw

	Water soluble K	Exch. K	Non-exch. K	Lattice K	Total K	K % in grain	K % in straw	Grain yield	Straw yield
Water soluble K	1								
Exch. K	0.559*	1							
Non-exch. K	0.499*	0.237	1						
Lattice K	0.138	0.25	0.067	1					
Total K	0.337	0.35	0.35	0.911**	1				
K % in grain	-0.407	0.544*	0.719*	0.048	0.351	1			
K % in straw	-0.323	0.332*	0.840**	0.024	0.374	0.934**	1		
Grain yield	0.374*	0.315*	0.809**	-0.022	0.317	0.938**	0.978**	1	
Straw yield	0.351*	0.277*	0.783**	-0.034	0.295	0.920**	0.968**	0.997**	1

****.** Significant at 1%

*****. Significant at 5%

Discussion

V DISCUSSION

The results of the field experiment on “Effect of levels and split application of potassium on productivity of paddy and status of potassium in alluvial soil of coastal region of Karnataka” conducted at Zonal Agricultural and Horticultural Research Station (ZAHRS), Brahmavar, located in Coastal Zone of Karnataka during *kharif* 2017 are discussed in this chapter.

5.1 Effect of potassium levels and its split application on growth and yield parameters paddy

Many factors, both external and internal influence the crop growth and productivity. Nutrient management is one such important factor which largely decides the yield of the crop produced. The economic yield of plant is an outcome of a series of integrated interactions of various biological events involving biochemical, physiological and morphological changes which take place during its development in accordance with the supply of light, water, temperature and nutrients (Donald, 1962). The grain yield depends on the synthesis and accumulation of photosynthates and their distribution among various plant parts. The synthesis, accumulation and translocation of photosynthates depend upon efficient photosynthetic structure as well as the extent of translocation into sink (grains) and also on plant growth and development during early stages of crop growth.

Results given in Table 3 and Fig. 3 to Fig. 5 showed that significantly higher grain (7733 kg ha^{-1}) and straw yield (8815 kg ha^{-1}) were produced by the application of 75 kg potassium in three equal splits followed by the application of 75 kg potassium in at two equal splits. Whereas, lower grain yield (5185 kg ha^{-1}) and straw yield (5963 kg ha^{-1}) was produced in no potassium application. Higher yield with 75 kg potassium application in three equal splits attributed to significantly higher yield parameters viz., plant height (115.05 cm), higher number of tillers per m^2 (482.25), panicle length (23.05 cm), thousand grain weight (25.34 g), number of filled grains per panicle (108.98) and lower chaffy grains per panicle (11.00) and was on par with 75 kg potassium application in two equal splits and was superior than other treatments (Table 2 and Table 3).

The yield of paddy showed higher stability due to split application of 75 kg potassium in three equal splits. Stability in yield may be ascribed to split application of potassium at active growth stages resulting in adequate potassium supply which increased plant photosynthesis rate because potassium is required in the activation of starch synthesis and then conversion of soluble sugars into starch is vital step in the grain filling process as reported by Ahmad *et al.* (1977) Mondal *et al.* (2005). Positive response of potassium application has been reported by Rajashekar (2010),

who reported that split application of potassium helps in longer availability for plant growth, hence increased the paddy grain yield and in heavy leaching of basal applied potassium resulted in reduced leaching losses and made available for crop growth for longer time under lateritic soils. Similar results of higher yield by split application of potassium were also reported by Krishnappa *et al.* (2006) and Gobi *et al.* (2008).

The significant increase in yield was due to balanced proportions of plant nutrient supplied through split doses to the crop as per need during the growth period resulting in a favourable increase in yield attributing characters which ultimately led towards an increase in economic yield.

Significantly lower grain yield (5184 kg ha⁻¹) and straw yield (5962 kg ha⁻¹) were produced by no application of potassium and this might be due to lesser availability of potassium for the growth of paddy which affected grain and straw yield. Similar results were evinced by Mitra *et al.* (2001).

5.2 Effect of potassium levels and it's split application on the potassium content of paddy at 30 DAT, 60 DAT and at harvest

It was observed from the results given in Table 4 and Fig. 6 that application of different levels and splits of potassium significantly increased the potassium content with increase in level of potassium application from 45 to 75 kg K₂O ha⁻¹ during all stages of crop growth. The highest potassium content of 1.97 per cent was recorded by treatment, T₉ (75 kg potassium application in three equal splits) compared to all other treatments. This may be due to increased availability of potassium in soil as indicated by positive and significant correlation observed between the exchangeable potassium status in soil and potassium content in grain and straw of paddy (Table 11). The increase in nutrient content in the plant was attributed to the increased level of potassium and better translocation of these nutrients from roots to other parts of the plants (Perumal *et al.*, 1969). Further, the nutrient content was found to be higher at initial stages and it decreased at later stages of crop growth probably because of dilution due to increased vegetative growth.

5.3 Effect of potassium levels and its split application on the uptake of potassium by grain and straw at harvest

Owing to increased supply of nutrients and increase in the grain and straw yield of paddy, application of potassium at different levels and splits significantly increased the uptake of potassium by straw and grain over T₁₀ (no potassium applied) Table 6 and Fig. 7. Further, it was noticed that split application of different levels of potassium was found to be superior in increasing

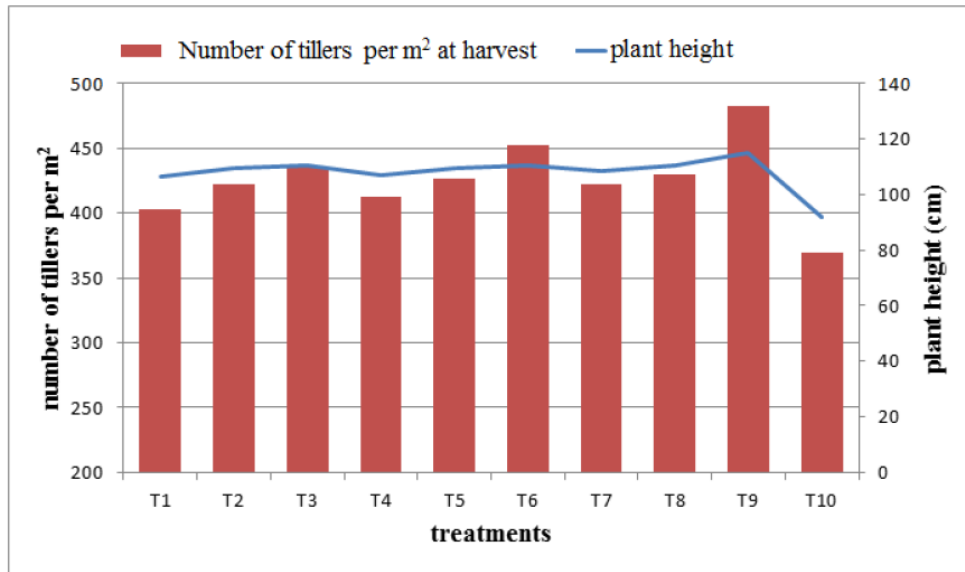


Fig 3: Effect of potassium levels and its split application on plant height and number of tillers per m²

T₁: 45 kg K₂O ha⁻¹ at basal

T₂: 60 kg K₂O ha⁻¹ at basal

T₃: 75 kg K₂O ha⁻¹ at basal

T₄: 45 kg K₂O ha⁻¹ in two equal splits

T₅: 60 kg K₂O ha⁻¹ in two equal splits

T₆: 75 kg K₂O ha⁻¹ in two equal splits

T₇: 45 kg K₂O ha⁻¹ in three equal splits

T₈: 60 kg K₂O ha⁻¹ in three equal splits

T₉: 75 kg K₂O ha⁻¹ in three equal splits

T₁₀: No K is applied

Two equal splits- first at time of transplanting and second at 55- 60 DAT

Three equal splits- first at time of transplanting, second at 25- 30 DAT and third at 55-60 DAT

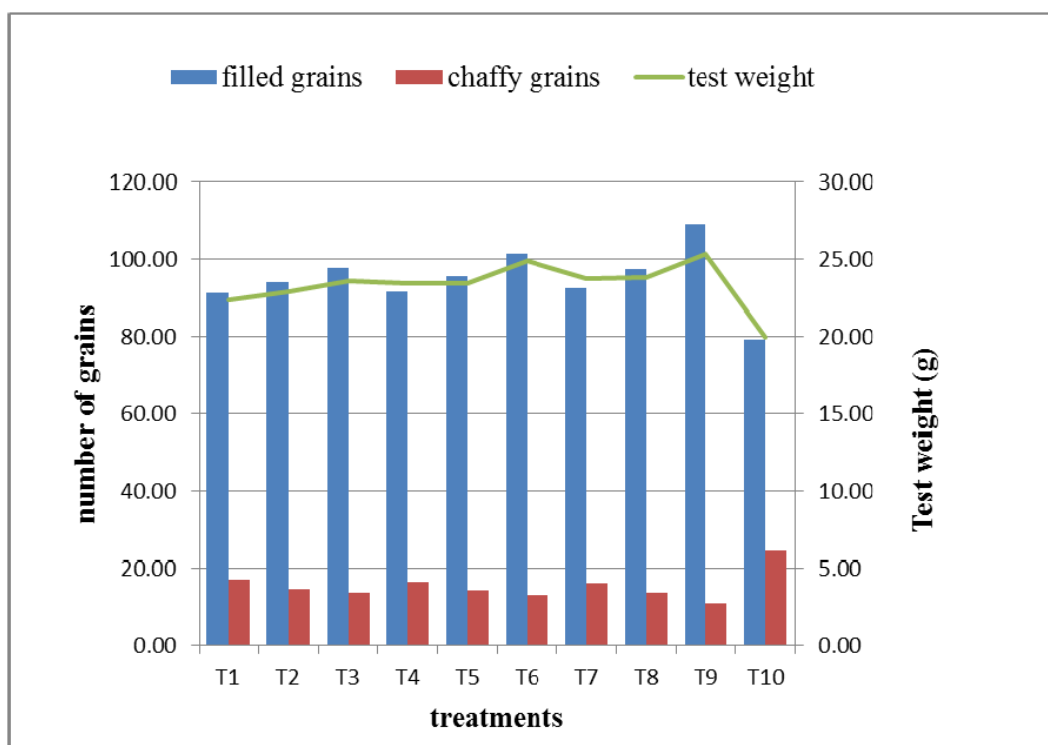


Fig 4: Effect of potassium levels and its split application on filled grains, chaffy grains per panicle and test weight of paddy grains

T₁: 45 kg K₂O ha⁻¹ at basal

T₂: 60 kg K₂O ha⁻¹ at basal

T₃: 75 kg K₂O ha⁻¹ at basal

T₄: 45 kg K₂O ha⁻¹ in two equal splits

T₅: 60 kg K₂O ha⁻¹ in two equal splits

T₆: 75 kg K₂O ha⁻¹ in two equal splits

T₇: 45 kg K₂O ha⁻¹ in three equal splits

T₈: 60 kg K₂O ha⁻¹ in three equal splits

T₉: 75 kg K₂O ha⁻¹ in three equal splits

T₁₀: No K is applied

Two equal splits- first at time of transplanting and second at 55- 60 DAT

Three equal splits- first at time of transplanting, second at 25- 30 DAT and third at 55-60 DAT

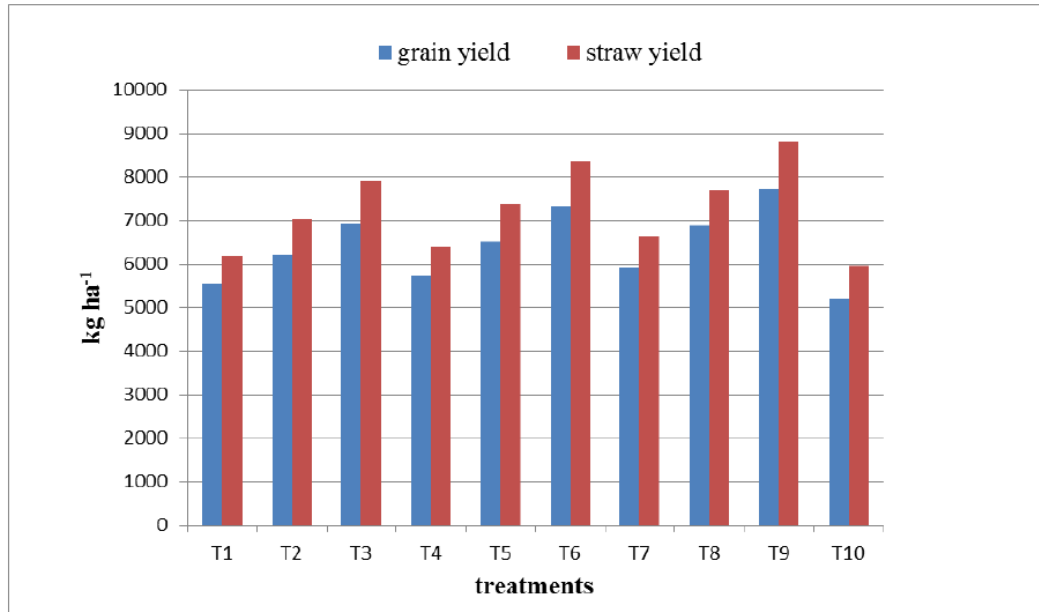


Fig 5: Effect of potassium levels and its split application on grain and straw yield of paddy

T₁: 45 kg K₂O ha⁻¹ at basal

T₂: 60 kg K₂O ha⁻¹ at basal

T₃: 75 kg K₂O ha⁻¹ at basal

T₄: 45 kg K₂O ha⁻¹ in two equal splits

T₅: 60 kg K₂O ha⁻¹ in two equal splits

T₆: 75 kg K₂O ha⁻¹ in two equal splits

T₇: 45 kg K₂O ha⁻¹ in three equal splits

T₈: 60 kg K₂O ha⁻¹ in three equal splits

T₉: 75 kg K₂O ha⁻¹ in three equal splits

T₁₀: No K is applied

Two equal splits- first at time of transplanting and second at 55- 60 DAT

Three equal splits- first at time of transplanting, second at 25- 30 DAT and third at 55-60 DAT

the uptake of nutrient by paddy. Uptake of potassium by straw (135.93 kg ha⁻¹) and grain (32.86 kg ha⁻¹) was significantly highest in treatment T₉ (75 kg potassium application in three equal splits). This indicates that application of potassium in split doses was found to be superior in increasing the potassium uptake by crop compared to basal and no potassium application (Sharma and Baruah (1997).

5.4 Effect of potassium levels and its split application on available potassium status in soil after harvest of paddy

It was noticed from the results in the Table 8 that available potassium in soil varied significantly. Highest available potassium (104 kg ha⁻¹) was recorded in T₆ (75 kg potassium application in two equal splits) and lowest was observed in no potassium application (T₁₀). This may be ascribed due to increased supply of potassium through potash fertilizers. Split application of potassium levels was found to be superior in increasing the available potassium status in soil compared to no potassium application because of decrease in its leaching losses from soil due to the split application (Muthuvel *et al.*, 1983 and Yadavamshi *et al.*, 1984).

5.5 Distribution of potassium fractions in soil at harvest of paddy.

Due to different potassium levels and splits (Table 9 and Fig 8a to Fig 8j), the water soluble and exchangeable potassium in soil at harvest of paddy significantly increased over the treatment no potassium application (T₁₀). The highest water soluble potassium (23.61 mg kg⁻¹) and exchangeable potassium (38.33 mg kg⁻¹) were observed in treatment with 75 kg potassium application in three equal splits (T₉) and 75 kg potassium application in two equal splits (T₆) compared to all other treatments. Application of higher dose of potassium increased the concentration of K⁺ in soil solution to a higher extent in sandy laterites compared to that of clayey soil (Bandhyopadhyaya and Goswamy, 1988). Similarly, Bar *et al.* (1986) reported that soil solution K was regarded as a function of exchangeable K present in illitic and kaiolinitic soils. Raskar and Pharande (1997) observed that higher exchangeable K in surface layer than that of subsurface layers due to higher crop residue yielding higher humus content and potash fertilizer in the surface layer and variation in clay content.

Similarly, potassium levels and split application significantly increased the non-exchangeable potassium in soil at harvest of paddy compared to all other treatments. However, maximum of 264.90 mg kg⁻¹ was observed in treatment receiving 60 kg potassium application in three equal splits (T₈) followed by 75 kg potassium application in two equal splits (247.91 mg kg⁻¹) and 75 kg potassium application in three equal splits (245.82 mg kg⁻¹) and lowest non exchangeable potassium of 137.39 mg kg⁻¹ was observed in no potassium application (T₁₀). This

suggests that some amount of added potassium might have transformed into non-exchangeable form due to dynamic equilibrium existing between water soluble, exchangeable and non-exchangeable forms.

Whereas, lattice potassium appeared to be a dominant fraction of total K and significantly increased over no potassium application. Higher lattice K was recorded in treatment receiving 45 kg potassium application in two equal splits followed by 60 kg potassium application in two equal splits. Similarly, total potassium in soil significantly increased over no potassium applied (1389 mg kg^{-1}) due to potassium levels and its split application. This suggests that dynamic equilibrium exists between all the forms of potassium.

The split application enables potassium availability at critical stages of plant growth thus avoiding the plant to suffer from potassium deficiency. This brings out clearly the superiority of split application of potassium.

Conclusion

- Application of 75 kg potassium in three equal splits was found to be best followed by 75 kg potassium application in two equal splits for higher productivity of paddy.
- Application of 75 kg potassium in two equal splits found to be best for maintaining potassium status in soil.
- More of water soluble potassium was found to best with application of 75 kg potassium in three equal splits, exchangeable potassium with application of 75 kg in two equal splits and non-exchangeable, lattice and total potassium found to be highest in 45 kg potassium application in two equal splits.

Future line of work

- Further investigations are required to study the split application of potassium on paddy under multi location trials.
- Further study needed for the response of different crops to potassium split application in potassium deficient soils.
- There is a need of studies on appropriate combinations of humic acids with potassium to reduce leaching losses, higher yield and better quality of rice.

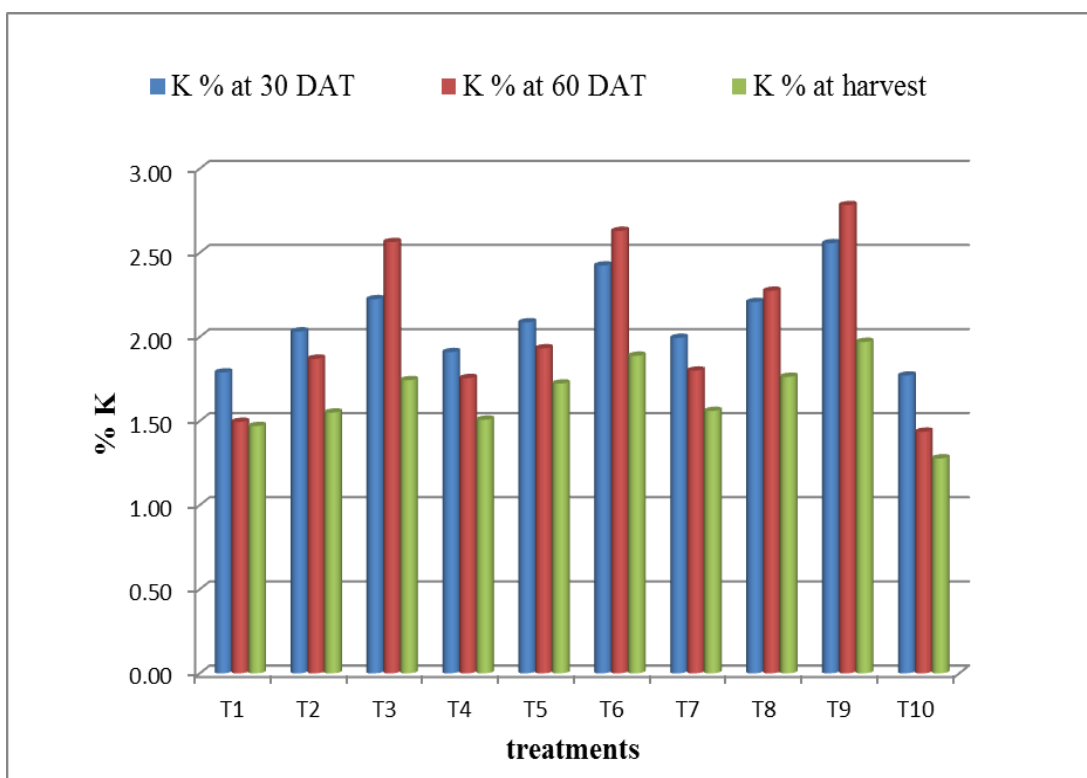


Fig 6: Effect of potassium levels and its split application on K content at 30 DAT, 60 DAT and at harvest

T₁: 45 kg K₂O ha⁻¹ at basal

T₂: 60 kg K₂O ha⁻¹ at basal

T₃: 75 kg K₂O ha⁻¹ at basal

T₄: 45 kg K₂O ha⁻¹ in two equal splits

T₅: 60 kg K₂O ha⁻¹ in two equal splits

T₆: 75 kg K₂O ha⁻¹ in two equal splits

T₇: 45 kg K₂O ha⁻¹ in three equal splits

T₈: 60 kg K₂O ha⁻¹ in three equal splits

T₉: 75 kg K₂O ha⁻¹ in three equal splits

T₁₀: No K is applied

Two equal splits- first at time of transplanting and second at 55- 60 DAT

Three equal splits- first at time of transplanting, second at 25- 30 DAT and third at 55-60 DAT

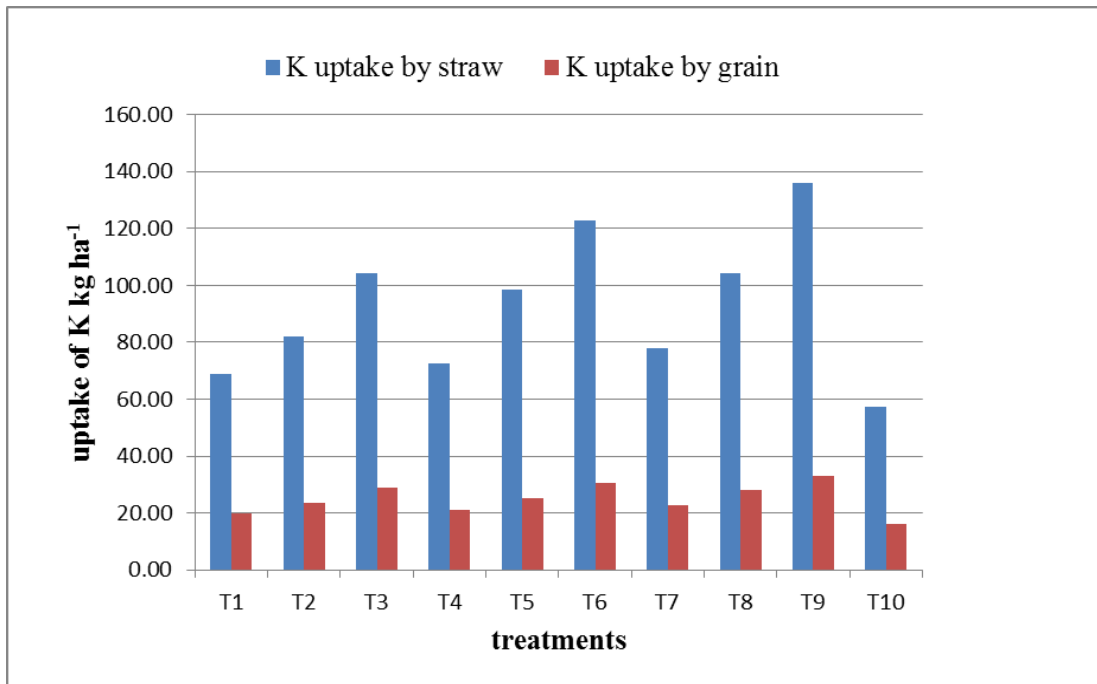


Fig 7: Effect of potassium levels and its split application on potassium uptake by paddy grain and straw

T₁: 45 kg K₂O ha⁻¹ at basal

T₂: 60 kg K₂O ha⁻¹ at basal

T₃: 75 kg K₂O ha⁻¹ at basal

T₄: 45 kg K₂O ha⁻¹ in two equal splits

T₅: 60 kg K₂O ha⁻¹ in two equal splits

T₆: 75 kg K₂O ha⁻¹ in two equal splits

T₇: 45 kg K₂O ha⁻¹ in three equal splits

T₈: 60 kg K₂O ha⁻¹ in three equal splits

T₉: 75 kg K₂O ha⁻¹ in three equal splits

T₁₀: No K is applied

Two equal splits- first at time of transplanting and second at 55- 60 DAT

Three equal splits- first at time of transplanting, second at 25- 30 DAT and third at 55-60 DAT

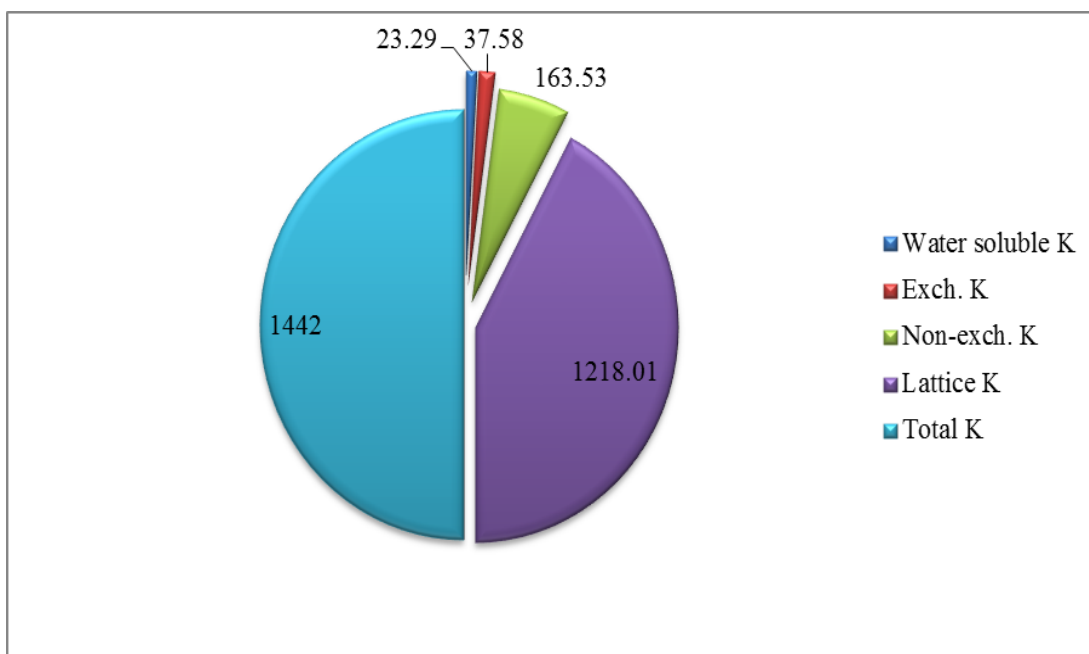


Fig 8a: Forms and distribution of potassium (mg kg⁻¹) in soil after harvest of paddy in treatment receiving 45 kg potassium as basal dose

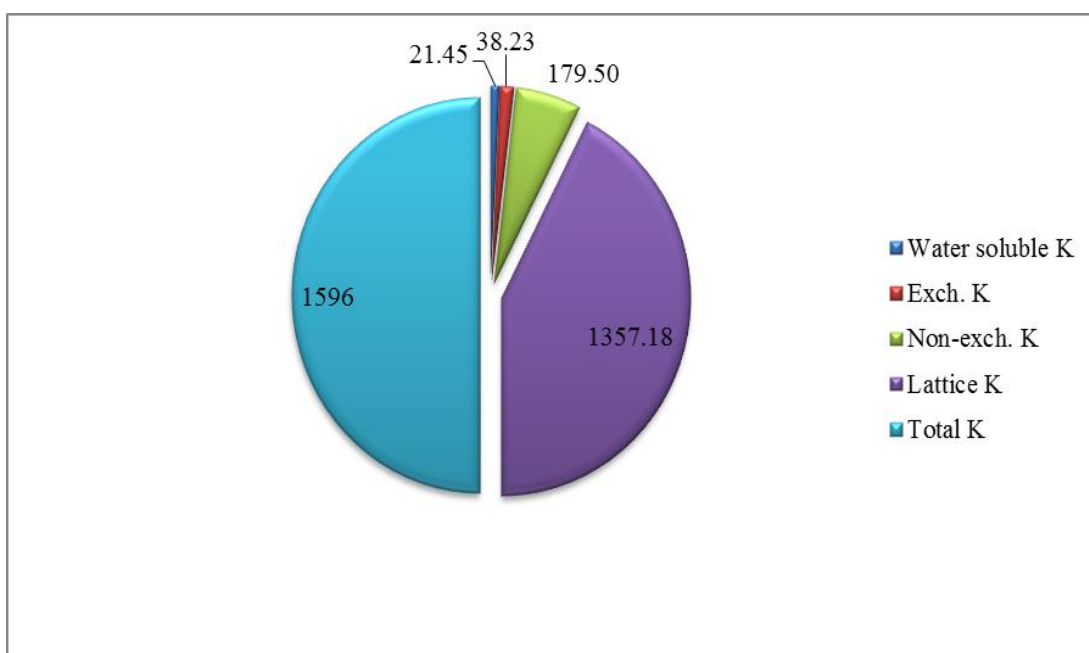


Fig 8b: Forms and distribution of potassium (mg kg⁻¹) in soil after harvest of paddy in treatment receiving 60 kg potassium as basal dose

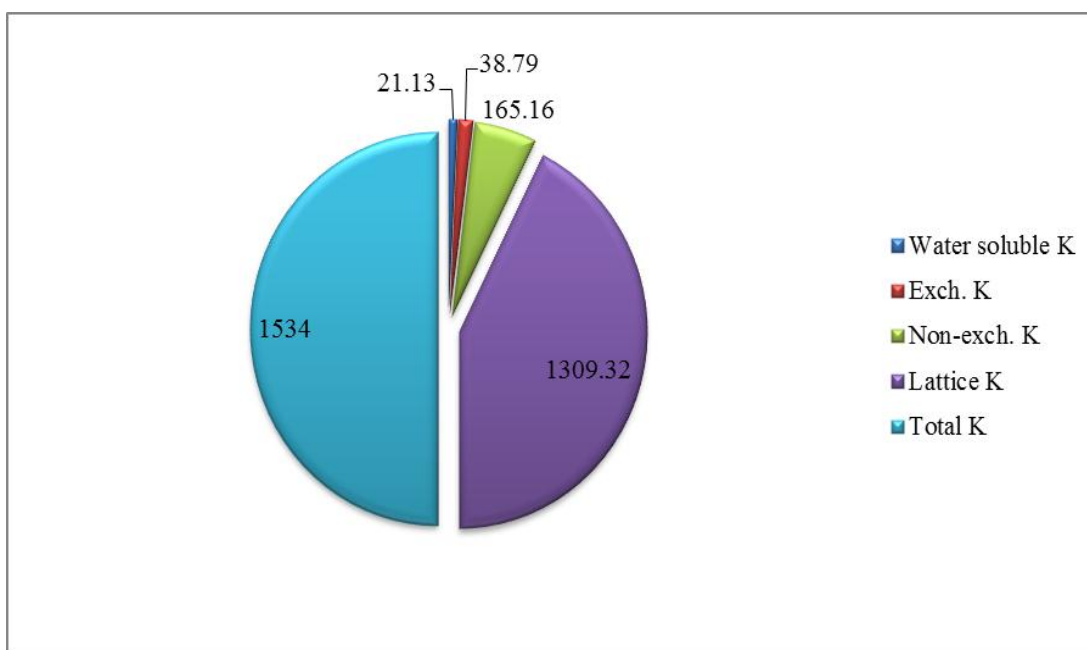


Fig 8c: Forms and distribution of potassium (mg kg⁻¹) in soil after harvest of paddy in treatment receiving 75 kg potassium as basal dose

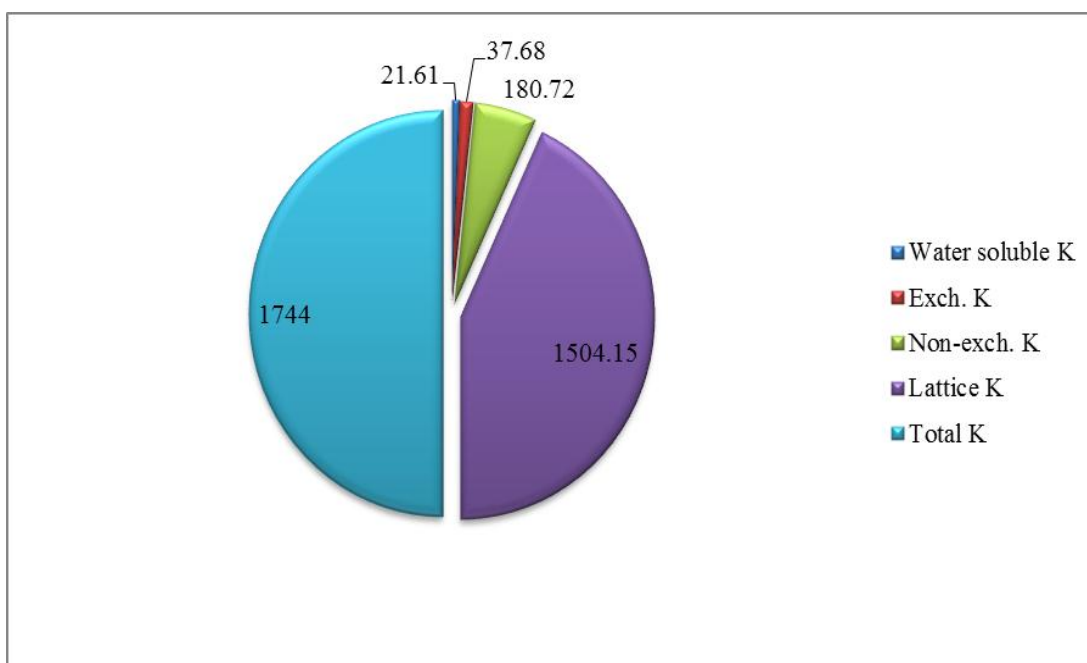


Fig 8d: Forms and distribution of potassium (mg kg⁻¹) in soil after harvest of paddy in treatment receiving 45 kg potassium in two equal splits

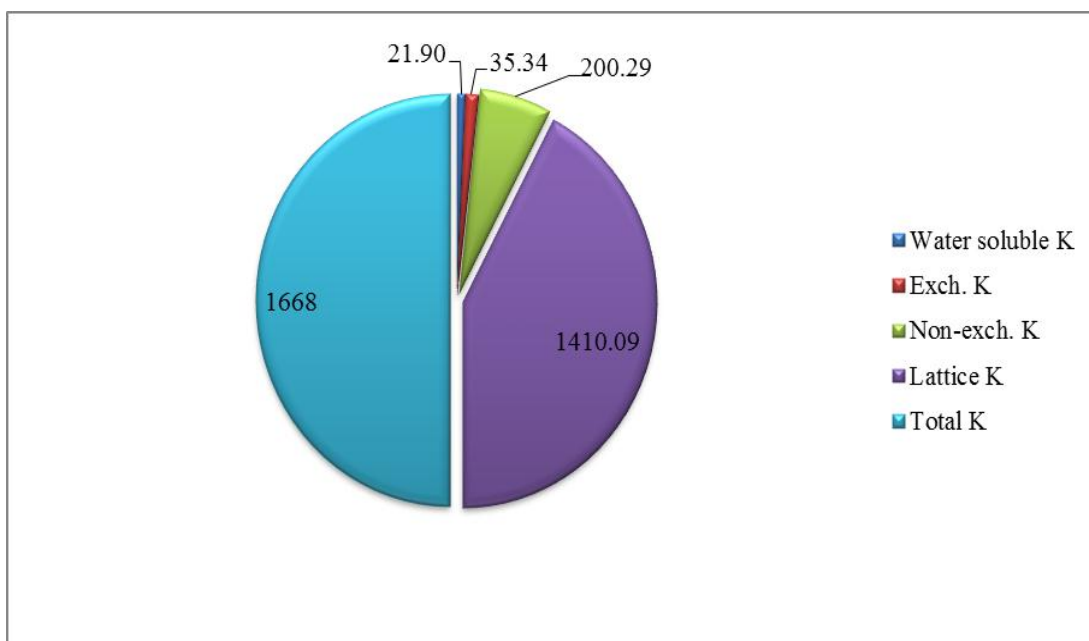


Fig 8e: Forms and distribution of potassium (mg kg⁻¹) in soil after harvest of paddy in treatment receiving 60 kg potassium in two equal splits

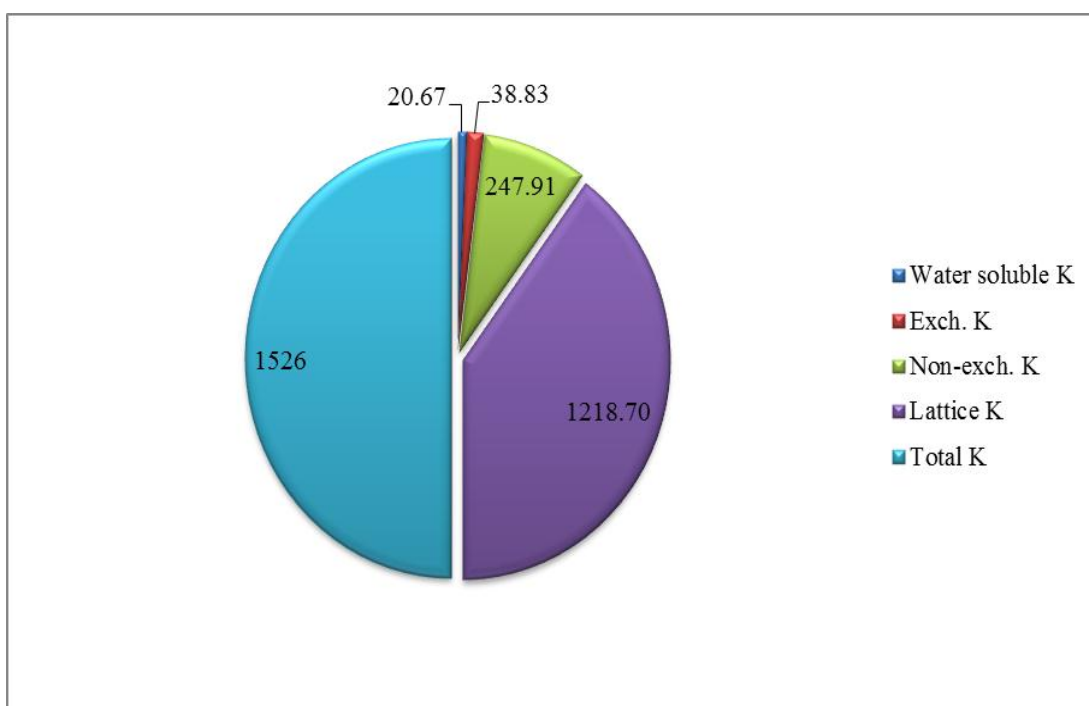


Fig 8f: Forms and distribution of potassium (mg kg⁻¹) in soil after harvest of paddy in treatment receiving 75 kg potassium in two equal splits

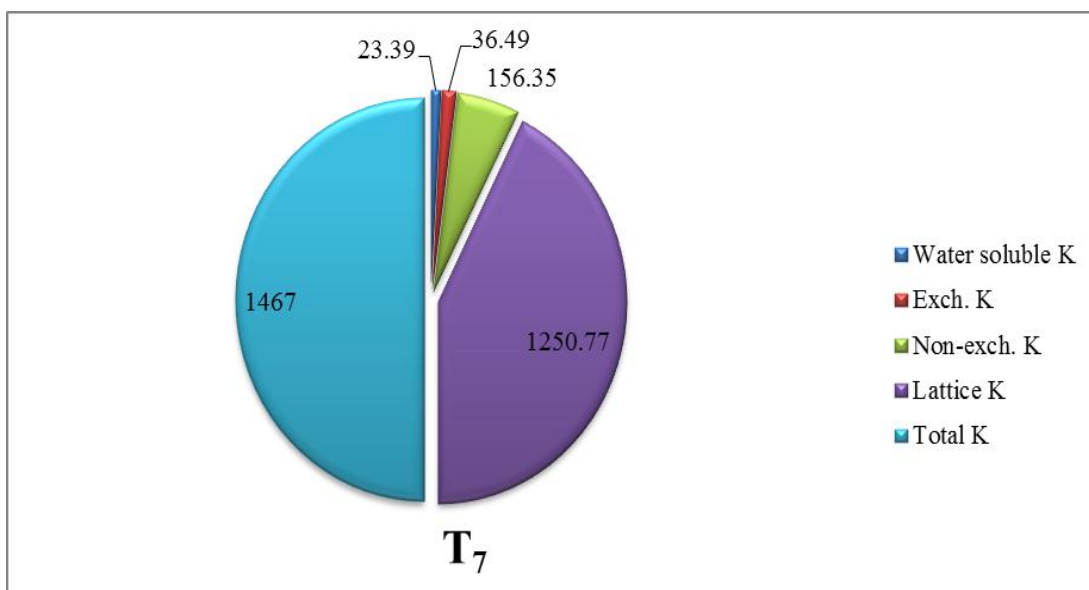


Fig 8g: Forms and distribution of potassium (mg kg⁻¹) in soil after harvest of paddy in treatment receiving 45 kg potassium in three equal splits

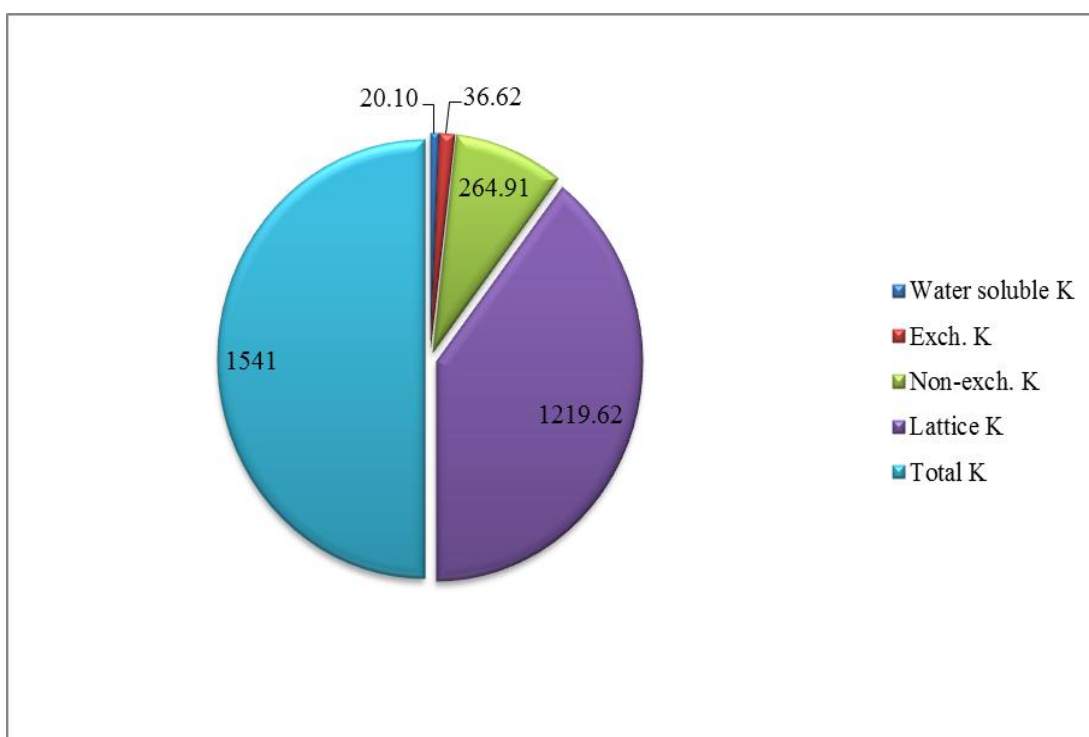


Fig 8h: Forms and distribution of potassium (mg kg⁻¹) in soil after harvest of paddy in treatment receiving 60 kg potassium in three equal splits

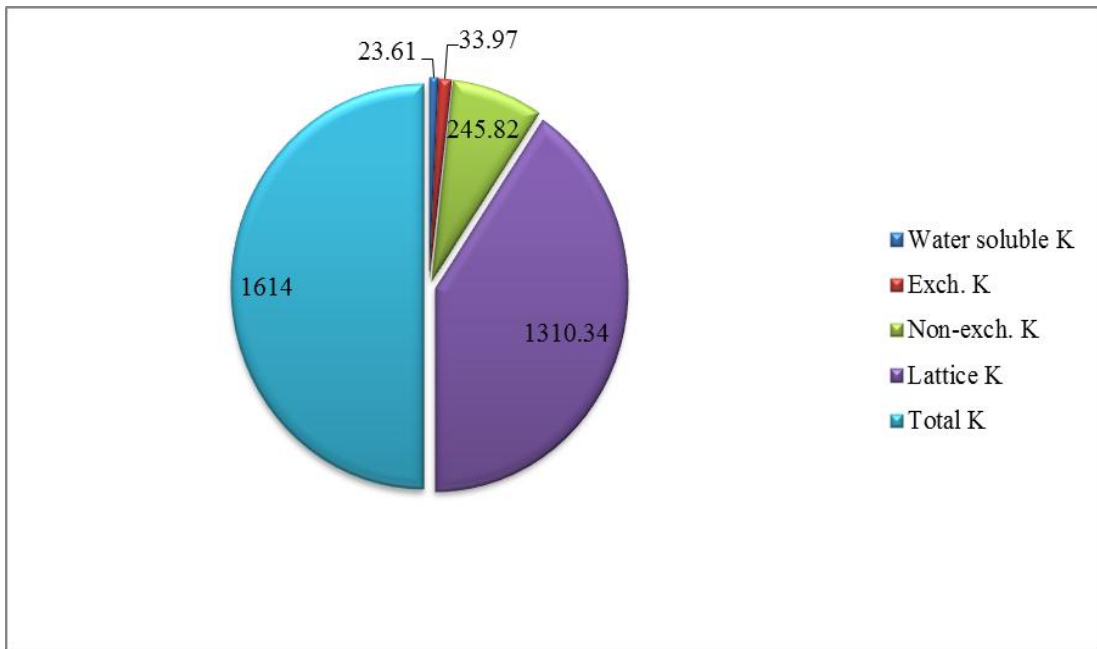


Fig 8i: Forms and distribution of potassium (mg kg⁻¹) in soil after harvest of paddy in treatment receiving 75 kg potassium in three equal splits

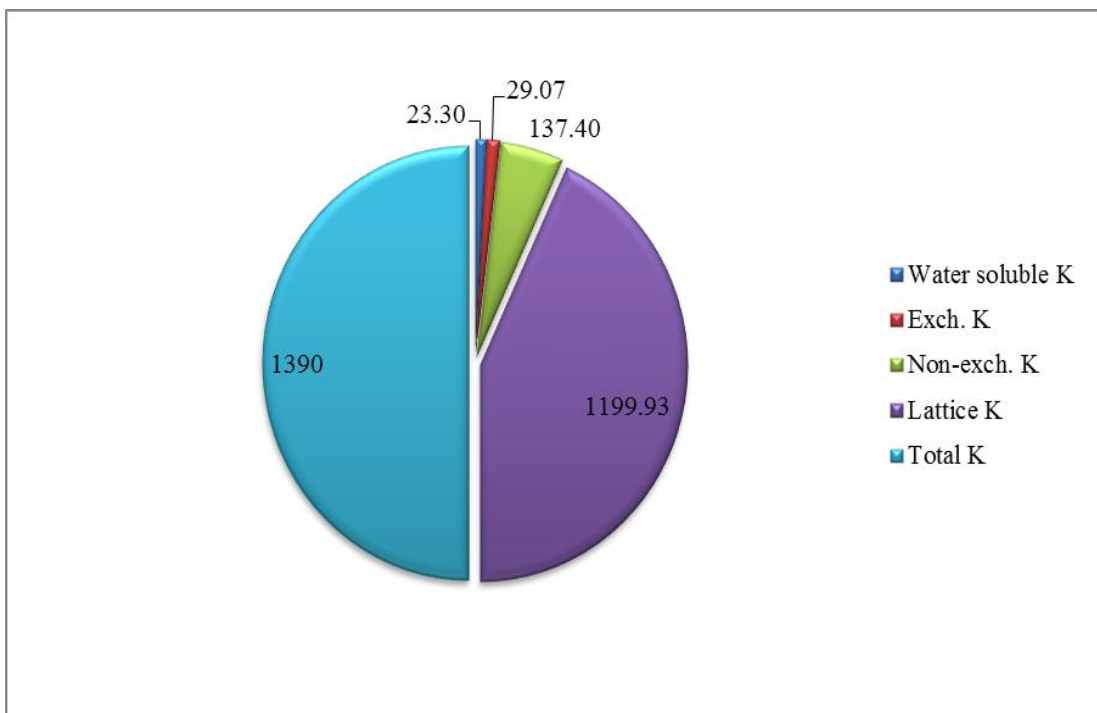


Fig 8j: Forms and distribution of potassium (mg kg⁻¹) in soil after harvest of paddy in treatment receiving no potassium

Summary

VI SUMMARY

An investigation on “Effect of levels and split application of potassium on productivity of paddy and status of potassium in alluvial soil of coastal region of Karnataka” was carried out on sandy loam soil at Zonal Agricultural and Horticultural Research Station (ZAHRS), Brahmavar, located in Coastal Zone of Karnataka during *kharif* 2017. The experiment was laid out in a Randomized Complete Block Design (RCBD) with ten treatments and four replications. The treatments consisted of different levels and splits of potassium, these treatments were compared with control (no potassium applied). The salient findings of the experiment conducted during the study are summarized here under:

- ✓ Application of 75 kg potassium in three equal splits recorded the highest grain and straw yield (7732 and 8815 kg ha⁻¹), followed by the application of 75 kg potassium in two equal splits (7331 and 8357 kg ha⁻¹).
- ✓ The highest number of filled grains per panicle (108.98) was observed in the treatment with application of 75 kg potassium in three equal splits followed with an application of 75 kg potassium at two equal splits (101.30).
- ✓ Significantly higher number of chaffy grains per panicle was recorded in treatment with no potassium application (24.67) and least was recorded in treatment with application of 75 kg potassium in three equal splits (11.00).
- ✓ The higher test weight was recorded with the application of 75 kg potassium in three equal splits (25.34 g) that differed significantly with the (19.97 g) no application of potassium.
- ✓ Significantly longer panicle length was recorded in treatment with 75 kg potassium application in three equal splits (23.05 cm). While the lower panicle length was recorded in no potassium application (20.92 cm).
- ✓ Significantly higher number of tillers per m² was significantly recorded in treatment 75 kg potassium application in three equal splits (482.25).
- ✓ Significantly higher plant height (115.05 cm) was recorded in treatment with 75 kg potassium application in three equal splits.
- ✓ The nutrient content of K in paddy at 30 DAT was recorded highest with the application of 75 kg potassium application in three equal splits, followed by 75 kg potassium application at two equal splits.

- ✓ The nutrient content of K at 60 DAT was recorded highest with application of 75 kg potassium in three equal splits followed by 75 kg potassium application in two equal splits.
- ✓ The nutrient content K in grain and straw was recorded highest with the application of 75 kg potassium application in three equal splits, followed by 75 kg potassium application in two equal splits and least was observed in no potassium treated plots.
- ✓ The same trend was followed in K uptake as noticed in the yield. The highest K uptake and K content were noticed in 75 kg potassium application in three equal splits, followed by 75 kg potassium application in two equal splits.
- ✓ The available soil potassium at harvest stage was significantly higher in 65 kg potassium application in two equal splits.
- ✓ Higher water soluble potassium (23.61 mg kg^{-1}) was recorded in 75 kg potassium application in three equal splits followed by 45 kg potassium application in three equal splits.
- ✓ Significantly highest exchangeable potassium (38.83 mg kg^{-1}) was observed in 75 kg potassium application in two equal splits and the non-exchangeable potassium recorded highest in 60 kg potassium application in three equal splits.
- ✓ Higher lattice potassium ($1504.15 \text{ mg kg}^{-1}$) was recorded in 45 kg potassium application in two equal splits and least (1199 mg kg^{-1}) was observed in no potassium application.
- ✓ The total potassium was recorded highest (1744 mg kg^{-1}) in 45 kg potassium application in two equal splits and lowest was recorded in no potassium application.

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