"EVALUATION OF CRITICAL LIMITS OF POTASSIUM IN SOIL AND PLANT FOR UPLAND PADDY GROWN ON SHRINK-SWELL SOILS".

By

Miss. SHINDE SAVITA RAVINDRA

(Reg. No. 11/115)

A Thesis submitted to the

**MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI - 413 722, DIST. AHMEDNAGAR,
MAHARASHTRA, (INDIA).**

In partial fulfilment of the requirements for the degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

**DIVISION OF SOIL SCIENCE AND
AGRICULTURAL CHEMISTRY**

**COLLEGE OF AGRICULTURE
KOLHAPUR – 416 004**

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APPROVED BY

(Dr. D. S. Patil)
Chairman and Research Guide

(Dr. A. L. Pharande)
Committee Member

(Prof. S. M. Jagtap)
Committee Member

(Prof. M. R. Shewale)
Committee Member

DIVISION OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE,
KOLHAPUR – 416 004

2013

CANDIDATE'S DECLARATION

I hereby declare that this thesis or a part

there of has not been submitted

by me or any other person

to any other University

or Institute for

a Degree or

Diploma.

Place : Kolhapur

Date : / /

(Miss. Shinde S. R.)

Dr. D. S. Patil
Associate Professor,
Division of Soil Science and Agril. Chemistry,
College of Agriculture, Kolhapur,
Dist. Kolhapur.
Maharashtra State (India)

CERTIFICATE

This is to certify that the thesis entitled, **"EVALUATION OF CRITICAL LIMITS OF POTASSIUM IN SOIL AND PLANT FOR UPLAND PADDY GROWN ON SHRINK-SWELL SOILS",** submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar (Maharashtra State) in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**, embodies the results of a piece of *bonafide* research work carried out by **Miss. Shinde Savita Ravindra,** under my guidance and supervision and that no part of the thesis has been submitted for any other Degree or Diploma or publication in other form.

Place: A. C. Kolhapur **(Dr. D. S. Patil)**
Date: / / Research Guide

Dr. G. G. Khot,
Associate Dean,
College of Agriculture,
Kolhapur – 416 004.
Maharashtra State (India)

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Place: A. C. Kolhapur (Dr. G. G. Khot)
Date: / / Associate Dean

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Place: *A. C. Kolhapur*

Date: */ /* ***(Miss. Shinde S.R.)***

CONTENTS

LIST OF TABLES

List of table contd......

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

%	:	Per cent
<	:	Less than
>	:	Greater than
@	:	At the rate of
°C	:	Degree celcius
C mol Kg^{-1}	:	Centi mol per Kilogram
$CaCO_3$	:	Calcium Carbonate
CD	:	Critical Difference
CEC	:	Cation Exachange Capacity
C.F.	:	Correction Factor
Cm	:	Centimetre (s)
Css	:	Corrected sum of square (s)
Cu	:	Copper
Cv.	:	Cultivar
DAS	:	Days After Sowing
DAT	:	Days After Transplanting
dS m^{-1}	:	Decisimen per metre
E	:	East
EC	:	Electric Conductivity
EDTA	:	Ethylene Diamine Tetra Acetic Acid
e.g.	:	Example
et al.	:	and other (et alli)
Fe	:	Iron
Fig.	:	Figure
FYM	:	Farm Yard Manure
g	:	Gram
g Kg^{-1}	:	Gram per Kilogram
g pot^{-1}	:	Gram per pot
H	:	High potassium status soils
H_2O_2	:	Hydrogen peroxide
$HClO_4$	:	Per chloric acid
HNO_3	:	Nitric acid
H_2SO_4	:	Sulphuric acid
ha	:	Hectare
ha^{-1}		Per hectare
Hr	:	Hour
i.e.	:	That is
K	:	Potassium
K_0	:	Absolute control (0 Kg K_2O ha^{-1})
K_{50}	:	Optimum level (50 Kg K_2O ha^{-1})

KAR	:	Potassium Activity Ratio
K_2O	:	Potash
Kg	:	Kilogram
Km	:	Kilometer
kg ha^{-1}	:	Kilogram per hectare
K_2SO_4	:	Potassium sulphate
L	:	Low potassium status soils
M	:	Medium potassium status soils
M	:	Molar
MOP	:	Muriate of Potash
Mn	:	Manganese
M	:	Meter
m^2	:	Meter square
m. ha.	:	Million hectare (s)
m. t.	:	Million ton (s)
me 100 g^{-1}	:	Milli equivalent per 100 gram
mg	:	Milli gram
mg ha^{-1}	:	Milli gram per hectare
mg Kg^{-1}	:	Milli gram per Kilogram
mg pot^{-1}	:	Milli gram per pot
mm	:	Milli metre
N	:	Normal
N	:	Nitrogen
N	:	North
$NaHCO_3$	:	Sodium bicarbonate
NH_4OAc	:	Ammonium Acetate
O.C.	:	Organic Carbon
P	:	Phosphorus
ppm	:	Parts per million
P_2O_5	:	Phosphorus pentaoxide
S.E.	:	Standard Error
SSP	:	Single Super Phosphate
TSS	:	Total sum of square (s)
t ha^{-1}	:	Tonne (s) per hectare
Viz.	:	Namely
v/s	:	Versus
Zn	:	Zinc

ABSTRACT

"EVALUATION OF CRITICAL LIMITS OF POTASSIUM IN SOIL AND PLANT FOR UPLAND PADDY GROWN ON SHRINK-SWELL SOILS."

by

Miss. Savita Ravindra Shinde

A candidate for the degree

of

MASTER OF SCIENCE (AGRICULTURE)

2013

Research Guide : Dr. D. S. Patil

Department : Soil Science and Agricultural Chemistry

The pot culture experiment was conducted during *kharif* season 2012 at College of Agriculture, Kolhapur to evaluate the critical limits of potassium in soil and plant for upland paddy grown on shrink-swell soils. Soils from eighteen different locations were collected having low (<125 kg K_2O ha^{-1}), medium (125-250 kg K_2O ha^{-1}) and high (>250 kg K_2O ha^{-1}) potassium status. The present investigation was carried out in Factorial Completely Randomized Design with two treatments (*viz.* 0 and 50 kg K_2O ha^{-1}) and two replications. The paddy crop was harvested at 100 per cent flowering. The observations of number of tillers, plant height and dry matter yield were recorded. The concentration and uptake of nutrients (N, P, K, Fe, Mn, Zn and Cu) of paddy plant were determined at 100 per cent flowering. The critical limits of potassium in soil and plant were worked out according to method of Cate and Nelson (1965 and 1971).

The results indicated that, the number of tillers per pot and height (cm) of paddy plant were significantly affected by potassium application. The number of tillers per pot ranged from 31.55 to 37.11 and plant height ranged from 58.94 to 66.31 cm. The dry matter yield (g pot^{-1}) of paddy plant ranged from 34.49 to 49.77 g pot^{-1} amongst 18 locations. There was a significant increase in dry matter yield due to application of potassium.

Application of potassium had also significantly influenced the concentration and uptake of macronutrients (N, P and K) and micronutrients (Fe, Mn, Zn and Cu) of paddy crop at 100 per cent flowering. The N uptake ranged from 0.39 to 0.80 g pot^{-1} and were significantly increased due to application of potassium. The P uptake ranged from 0.02 to 0.05 g pot^{-1} which indicated the significant response to potassium application.

The potassium concentration in paddy plant at 100 per cent flowering ranged from 1.02 to 1.24 per cent and were significantly increased due to application of potassium. The potassium uptake were significantly increased due to potassium application and ranged from 0.35 to 0.62 g pot^{-1}.

The critical limit of potassium in soil for paddy plant was found 264.22 kg K ha^{-1} by graphical method of (Cate and Nelson, 1965) and 268.80 kg K ha^{-1} by statistical method of (Cate and Nelson, 1971), respectively. The critical limit of potassium in paddy plant at 100 per cent flowering for shrink-swell soils was found 1.39 per cent by graphical method (Cate and Nelson, 1965) and 1.41 per cent by statistical method (Cate and Nelson, 1971), respectively.

Abstract contd..... **Shinde S. R.**

The results indicated that, soil containing less than 268.80 kg K ha^{-1} and paddy plant containing less than 1.41 per cent potassium at 100 per cent flowering, respond to application of potash fertilizers.

Correlation coefficients between initial soil chemical properties and nutrients uptake without K showed that the soil potassium was significantly positively correlated with all nutrients uptake without potassium.

Page No. 1 to 74.

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1. INTRODUCTION

Rice (*Oryza sativa* L.) is a major *Kharif* crop of India. Rice is foremost cereal crop of the world and is the staple food of over 60 per cent of the worlds population. In India, particularly Southern and Western India, rice is the main constituent of the daily diet. Other rice products of common importance are parched rice (Murmura), beaten rice (Poha) and parched paddy (Lahi). Most of the paddy is consumed by human being after cooking as whole rice or by preparing products like Bhakri, Idali, Dossa or Uttappa. Rice cultivation in India is traditionally confined to the areas of high rainfall, where it is grown under lowland conditions. But with the use of irrigation resources and introduction of high yielding cultivars, rice is being cultivated under upland conditions in nontraditional areas in Maharashtra. Upland rice is grown on soils that are aerobic or oxidized for the greater part of the growing season (Ponnamperuma, 1975).

Rice occupies 23.3 per cent of gross cropped area of the country, contributes 43 per cent of total grain production and 46 per cent of total cereal production. Considering world wide distribution India has the largest area under rice cultivation (42.49 m. ha) and has occupies second position in production (88.28 m.t) next to china. In India, as far as area concerned under rice, Uttar Pradesh ranks first (58.39 lakh hectares.) followed by West Bengal (54.36 lakh hectares) and Orissa (44.34 lakh hectares). In terms of production, West Bengal ranks first (124.28 lakh tones) followed by Uttar Pradesh (115.40 lakh tones) and Andhra Pradesh (114.48 lakh tones).

According to agricultural statistical information of Maharashtra, rice is second important crop, grown over an area of 15.35 lakh hectares. The average productivity of the state is 1.85 tones per hectare. Area under rice crop in Kolhapur district is 1.10 lakh hectares with average productivity of 2.35 tones per hectare. The position of Maharashtra in rice production is comparatively poor. In the state, rice is grown in the districts with varying extent. However, the major rice growing districts are Raigad, Thane, Ratnagiri and Sindhudurg of Konkan region, Kolhapur district of western Maharashtra region and Bhandara, Chandrapur and Gadchiroli of Vidharbha region. (Anonymous, 2006).

The world wide experience shows that more than 50 per cent of the increase in crop yield is due to fertilizers (Braun and Roy, 1983). Potassium (K), one of the three major essential plant nutrients acts as a master cation of the plant nutrient and involves in many physiological and biochemical functions of plant growth and yield processes. Clay minerals like muscovite and biotite are the most important sources of soil potassium (Rich, 1972). They hold the bulk of mobile potassium and release it when the concentration of soil solution falls due to plant uptake and leaching. As essential plant nutrient, potassium is known to perform several functions in plants such as assistance in the synthesis and translocation of carbohydrates, protein synthesis, improvement in nitrogen utilization, enhanced resistance of plants to withstand pests, diseases and stress conditions and improvement in plant quality. Potassium is absorbed by plants in larger quantities than any other element;

except N (Krauss, 1997). Potassium plays a vital role as macronutrient in plant growth and sustainable crop production (Marschner, 1986). It maintains turgor pressure of cells which is essential for cell expansion. It helps in osmo-regulation of plant cell, assists in opening and closing of stomata (Mengel and Kirkby, 1987). It plays a key role in activation of more than 60 enzymes (Tisdale et. al., 1990). It is known for its interaction both antagonistic and synergistic with essential macro and micro nutrients (Dibb and Thomson, 1985). Potassium addition increases tissue levels in plants and about 80-90 per cent of potassium absorbed by the plants is found in straw (Rice Production Manual, 1967). An adequate supply of potassium confers drought tolerance and frost resistance in plants (Kemmler and krauss, 1989).

A concept of critical limit of nutrients was introduced by Ulrich (1959) and Smith (1962). However, the graphical method (Cate and Nelson, 1965) and later the statistical approach given by (Cate and Nelson, 1971) are being widely used for establishment of critical limit of a nutrient. Critical limit is the level of soil available nutrient above which that nutrient is no longer a primary limiting factor. Critical limits in soils and plants helps for making fruitful recommendations to specific crops in a typical soil. It is the limit which isolates the deficient plants or soils from the non-deficient ones. Deficiency symptoms, nutrient concentration, nutrient uptake, percentage yield and response of plants to applied nutrients are the common parameters used for establishing the critical limits. The response of plant nutrients either in terms of growth or yield is the best criteria. Critical limits varies depending on the soil types, crop and varieties, soil test methods and seasonal variations. According to the rating low, medium and high categories for potassium are <125, 125-250 and >250 Kg K_2O ha^{-1} respectively. However as per this rating almost all black soils having high clay content, showing high availability of potassium in soil. But even though most of the crops shows positive response to potassium application. There is ambiguity in potassium rating, so to confirm specific rating for available potassium in shrink-swell soils, the study of critical limit of potassium is necessary.

Information in respect to potassium nutrition in rice is very meager. The critical concentration of potassium in rice plant and soil for better yield is also not studied in rational way. Subba Rao *et. al.* (2010) reported critical limits of potassium in rice, wheat, sorghum, cotton and groundnut. The understanding of critical limits for soil and plant is very essential, at present the very limited information is available on critical limit of shrink-swell soils and plant for upland paddy. In view of this present investigation were taken to evaluate critical limits of potassium in plant and soil for rice crop at the Division of Soil Science and Agricultural Chemistry, College of Agriculture, Kolhapur during the *kharif* season 2012 with the following objectives:

1) To determine critical limit of potassium in shrink-swell soils and plant for upland Paddy.
2) To study the correlation coefficient between soil properties and nutrient uptake by upland Paddy.

2. REVIEW OF LITERATURE

An attempt has been made to compile the available information on critical limit of potassium under pot culture experiment. The existing literature in respect of various aspect of present investigation has been reviewed and presented briefly under the following appropriate heads.

2.1 Potassium fertility status of soils (Maharashtra).

2.2 Potassium fractions in soils.

2.3 Critical limits of potassium in soil and plant.

2.4 Potassium role in growth and development metabolism.

2.5 Response of paddy crop to potassium.

2.6 Soil potassium release capacity.

2.7 Effect of potassium on plant nutrients concentration.

2.8 Effect of potassium on plant nutrients uptake.

2.9 Correlation of potassium with plant nutrients uptake.

2.1 Potassium fertility status of soils (Maharashtra).

Subba Rao and Srinivasarao (1996) studied on established agro-ecological regions of NBSS and LUP, Nagpur and published information on available and reserve potassium of soils, different agro-ecological regions have been categorized for potassium fertility. It indicated that many regions i.e., 14, 15, 19, 8 and 12 were low in available K. Regions 2, 7, 20, 14, 15, 19, 8, 12, and 21 were having soils of low reserve K.

Hasan (2002) reported soil test results for potassium (K) fertility status among India's agricultural soils are categorized as, 21 per cent low, 51 per cent medium, and 28 per cent high. Thus, 72 per cent of India's agricultural area, representing 266 districts, needs immediate potassium fertilization.

Patil *et al.* (2010) reported spatial variability in fertility status of surface soils in Dharwad district and concluded that soils were moderately alkaline in reaction with normal electrical conductivity (EC). Organic carbon content in the soils was low in majority of the area (683 ha) while it was medium in the remaining area (350 ha). Available nitrogen content was low in 488 ha and medium in 544 ha. Available phosphorus was medium in 622 ha and low in 256 ha and high in the remaining area of 154 ha. The soils in the study area were high in available potassium status.

Survase *et al.* (2011) studied the fertility status of soil and nutrients recommendations in Panchaganga basin (Maharashtra) and found that most of the areas of the study region are fertile in nature. However low and very low fertility of soil was noted in some pockets only. The physiography, climate and agricultural activities have greatly influenced the nutrients status of soil. Specific fertilizers and addition of organic matters were recommended for nutrients deficient areas to keep the balance of nutrients and to restore the fertility of soils.

Deshmukh (2012) studied on the soil fertility status from Sangamner area, Ahmednagar district, (Maharashtra). Total 62 surface soil samples were analysed and reported that, the pH ranged from 8.0 to 9.7 reflecting alkaline nature of soils. Higher EC in the downstream part reflecting low flushing rate and sluggish ground water movement in the area. Organic carbon ranged from 0.17 to 1.58 per cent in the soils. The overall 29.03 per cent and 48.38 per cent of soils showed low and medium status of organic carbon, respectively. The available nitrogen and phosphorus contents were low, while available potassium was high.

2.2 Potassium fractions in soils.

The forms of potassium in order to their availability in plants and microbes are water soluble, exchangeable, non-exchangeable and total potassium. These all forms are in dynamic equilibrium.

Dhillon and Dhillon (1994) assessed some benchmarks shrink-swell soils of India. They indicated that smectitic shrink-swell soil contained largest amount of exchangeable potassium (0.68 cmol kg^{-1})and the largest amount of total potassium observed was 14.87 cmol kg^{-1} to 27.85 cmol kg^{-1}.

Raskar and Pharande (1997) observed the water soluble potassium of some shrink-swell soils series of Western Maharashtra and it was in the range of 4.20 to 20.50 mg Kg^{-1} with a mean value of 10.60 mg kg^{-1} and total potassium content ranged from 0.17 to 0.80 per cent with mean value of 0.50 per cent.

Thippeswamy *et al.* (2000) concluded that among different fractions of potassium, available potassium fraction increased with increase in potassium doses up to 80 kg K_20 ha^{-1} and split application of potassium also increased the available potassium fraction in red soils of Bangalore.

Majumdar *et al.* (2002) conducted a field experiment in a *hapludalf* to study the changes in different fractions of potassium in soil. They noticed that available potassium, exchangeable potassium, fixed potassium increased significantly with increasing doses of potassium and FYM. Total potassium was remained almost unchanged even though the potassium fertilizer was applied.

Subehia *et al.* (2003) conducted a field experiment to know the effect of levels of potassium and FYM on different forms of potassium during the different crop growth stages of potato. The results revealed that water soluble potassium played significant role in meeting out potassium needs at tuberization stage of potato crop.

2.3 Critical limits of potassium in soil and plant.

Kumar *et al.* (1991) studied critical limit of potassium in soil series and reported that the critical limit of potassium in soils and concentration in wheat plant as 110 kg K ha-1 and 1.2 per cent potassium, respectively.

Brar and Brar (1992) reported that critical potassium concentration in wheat plant at flag leaf stage and in straw at maturity were 1.30 and 1.10 per cent, respectively.

Cox and Uribe (1992) determined the critical level of potassium in plant tissue at flowering stage were 13 g kg^{-1} in corn and 12 g kg^{-1} in soybean. The critical exchangeable potassium levels of corn were 110 kg ha^{-1} on the loam soils and 90 kg ha^{-1} on the sandy loam soils, while for soybean it was 75 kg ha^{-1} for both the soils.

Prasad and Prasad (1992) studied critical levels for 1*N* ammonium acetate-extractable potassium for rice soils has been reported to vary from 0.17-0.21 cmol K kg^{-1}.

Bansal *et al.* (1993) reported that the effect of N application on dry matter production of rice was more prominent than of potassium during the initial stages of crop growth (30 and 45 DAT). Nutrient composition of both grain and straw at harvest was influenced by N and K application. Potassium application also increased the physiological efficiency of N at all levels of fertilizer application and the highest physiological efficiency index of 85 was observed with N_{100} K_{60}. Critical levels of potassium in plant tissue were influenced by N application and 1.92 to 2.15 per cent potassium in top two leaves at the end of tillering was recommended as critical level of potassium at optimum N supply.

Gajbhiye *et al.* (1993) using cotton, sorghum and wheat as a test crops and established a critical limit, 165 mg kg^{-1} soil of ammonium acetate potassium in Vertisols. They also showed that yield of the test crops increased beyond the level of 200 mg kg^{-1} soil.

Jeyabaskaran and Raghupathy (1993) studied critical limit of potassium for maize in Valuthalakudi soil series. They reported critical limits of potassium in Valuthalakudi series for neutral normal NH_4OAc and boiling concentrated HNO_3 were 160 and 730 kg K ha^{-1} respectively. The critical limit of potassium for maize plant was 1.4 per cent.

Tiwari, *et. al.* (1995) recorded the critical limit of potassium for wheat grown on *Typic Ustrochrepts*. They observed that critical concentration of potassium in six week old plants of wheat was 2.7 per cent under green house condition.

Ghosh and Mukhopadhyay (1996a) conducted a pot culture experiment using rice as a test crop and studied the critical limits of potassium in rice plant in Belar (fine, mixed, hyperthermic *vertic Hapla quept*) and Bankati (fine, mixed, hyperthermic *Aericochraqualf*) series of West Bengal. The Bray's per cent yield, per cent potassium content and potassium uptake by rice plant were significantly correlated with water soluble, available, reserve, non-exchangeable and total potassium. The data confirmed that the existing critical level of 113 kg ha^{-1} is applicable to the soils of Belar and Bankati series.

Ghosh and Mukhopadhyay (1996b) studied the status and critical limits of potassium in soils and plants of Jagannathpur and Barakonda soil series of West Bengal. They observed the critical limits of potassium in soils and concentration in mustard plant were found to be 90 kg ha^{-1} and 3.1 per cent, respectively in the Jagannathpur and 84 kg ha^{-1} and 3.02 per cent, respectively in Barakonda series. The Bray's per cent yield was positively and significantly correlated with available potassium and potassium uptake by mustard plant.

Kale and Chavan (1996) studied critical limit of potassium in relation to paddy yield in Kumbhave soil series of Konkan region. The critical potassium limits, calculated from a graph of Bray's per cent yield v/s soil available potassium, gave a value of 194 kg K ha^{-1}. Exchangeable potassium and available potassium had significant positive relationships with both grain and straw yield of rice grown under control conditions without potassium application, but only with grain yield when potassium was applied at 50 kg K ha^{-1}.

Rao and Takkar (1997) also recorded critical potassium content in smectites soil for sorghum was 240 mg ha^{-1} soil and critical potassium content in flag leaf and in shoot of sorghum were 2.52 and 1.25 per cent, respectively.

Golakiya (1999) studied the soil critical limit of potassium in *Vertic Ustochrepts* of Western India which was 145 kg ha^{-1}. Similarly, the critical concentration of potassium in groundnut pod at 30 DAS and in haulm at harvest was 0.9 and 0.46 per cent, respectively.

Tiwari *et al.* (1999) compared soil test methods and potassium critical limits for rice and concluded that the response to added potassium were significant in soils testing medium in both exchangeable and non-exchangeable potassium. The critical leaf potassium concentration in six week old rice plants was 1.8 per cent.

Singh *et al.* (2000) studied on soil test methods and critical limits of potassium for rice grown on *Typic Ustochrepts* and reported that the critical limit of potassium in rice plant at flowering stage was 1.92 per cent.

Singh *et al.* (2001) studied the critical limits of potassium in sugarcane plant and soil. Results showed that, the available potassium level in soil and different doses of potassium significantly affected cane yield. Generally, the increase in yield was noted with an increase in available potassium level of the soil as well as with the rates of applied potassium. The obtained critical limit in soil and plant was 149.0 kg ha^{-1} and 1.68 per cent potassium, respectively.

Bedi *et al.* (2002) studied the evaluation of a suitable extractant for available potassium for subtropical soils of Jammu region and resulted that critical limits of soil potassium extracted by NH_4OAc, H_2SO_4, HNO_3, Morgan's reagent, distilled water and $CaCl_2$ were 82, 82, 870, 41, 44 and 19 mg kg^{-1}, respectively. The critical limit for plant potassium was observed 1.25 and 1.8 per cent at 46 and 60 days of crop growth, respectively.

Murthy and Alivelu (2004) studied critical limits of potassium for castor in Alfisols. Critical limits determined by linear plateau method showed a significant unadjusted R^2 values i.e. greater than 0.98. Critical limit of different forms of potassium in soil with various extractants was also determined by both methods and the critical values were found to be nearly similar.

Hadvani *et al.* (2004) studied the critical limits of potassium in soil and plant and response of groundnut (*summer)* in medium black calcareous soils of Saurashtra and reported that the critical potassium concentration in groundnut at 30 DAS and maturity was found to be 0.94 and 0.46 per cent, respectively.

Subba Rao and Sammi Reddy (2005) compiled critical limits of available potassium in different crops (rice, wheat, sorghum, maize, pearl millet, groundnut, potato, cotton and chickpea.) on some well defined soils of Maharashtra. The data showed a great diversity in the critical limits of potassium ranging from 76 to 335 mg kg^{-1} soil.

Hadvani et al. (2007) studied the response and critical limits of potassium for wheat grown on medium black calcareous soils of Saurashtra. They were found that critical limits of available potassium in soil and concentration of potassium in wheat at 30 DAS and maturity was 155 kg ha^{-1} in soil, 1.4 and 1.8 per cent in plant.

Athokpam *et al.* (2009) studied the critical limits of potassium in relation to growth and development of French bean in acid soils of Manipur and reported that addition of potassium in the soils significantly increased the dry matter production and potassium uptake by the crop. The critical levels of potassium in soil and 40 days old plants below which response of French bean to potassium fertilization may be expected were 145 kg ha^{-1} of potassium in soil and 2.2 per cent potassium in plant, respectively.

2.4 Potassium role in growth and development metabolism.

Zia *et al.* (1987) studied on potassium nutrition of rice in a pot culture experiment by dipping seedling roots in a 0.7 per cent solution of K_2SO_4 for 72 hrs before transplanting resulted in significantly taller plants, more of productive tillers per plant, higher straw and grain yield.

Panda and Panda (1993) studied on evaluation of some potassium soil tests for rice in a *Fluventic Ustochrept* and reported that with variation in soil potassium fertility, marked variations were recorded for dry matter yield (13.5 to 32.7 g pot^{-1}). The corresponding relative yields ranged from 53.5 to 97.7g pot^{-1}.

Ghosh and Mukhopadhyay (1996a) studied the critical limit of potassium in rice plant in Belar and Bankati series of West Bengal and reported that the dry matter yield obtained in both the series showed that the dry matter yield increased significantly with increasing levels of potassium application up to 40 mg kg^{-1} soil.

Prasad and Chauhan (2000) studied the rice response to rate and time of application of potassium in an upland ecosystem and reported that application of 50 kg K_2O ha^{-1}, ½ basal and ½ at tillering had significantly more number of grains and filled grains per panicle, than the basal application of 25 and 50 kg K_2O ha^{-1}. Split application of K_2O also had higher values of effective shoots/m^2, panicle length and 1000 grain weight than the basal application of same amount of K_2O.

Singh *et al.* (2000) studied on effect of levels and phases of potassium application on growth and yield of rice and wheat and reported that plant height, number of shoots and dry matter accumulation in rice were significantly increased by the application of potassium over absolute control. An application of potassium significantly affected the increase of the growth characters of wheat., i.e. plant height, number of shoots and dry matter accumulation over no potassium application.

Fageria (2004) studied on dry matter yield and nutrient uptake by lowland rice at different growth stages and reported that dry matter yield of shoot was significantly increased and having quadratic response in relation to plant age.

Sung *et al.* (2004) studied on plant height, dry matter yield and forage quality at different maturity of whole crop rice and reported that plant height was 77 cm at the booting stage, which was lower when compared to the other stages among which the heights did not differ, with average range of 93-97 cm. The highest dry matter yield was observed at the yellow ripe stage (22.8 tonnes ha^{-1}), which was followed by the dead ripe stage (19.3 tonnes ha^{-1}), full ripe stage (19.3 tonnes ha^{-1}), and dough stage (15.1 tonnes ha^{-1}).

Singh (2004) studied the response of rice varieties to potassium levels in an acidic peat soil of Manipur Vally and reported that the height of the rice plants was unaffected by potassium levels but the number of effective tillers per hill increased significantly at different levels of potassium fertilization and maximum number of tillers was produced with 60 kg K_2O ha^{-1}.

Fageria and Knupp (2013) studied on upland rice phenology and nutrient uptake in tropical climate and reported that plant height, number of tillers per plant, number of leaves on main culm and maximum root length increased significantly in quadratic fashion with increasing plant age.

2.5 Response of paddy crop to potassium.

Recent reviews prepared on crop response to potassium in different soils of India which indicated positive response to potassium application in most of the areas, Subba Rao and Srinivasarao, (1996) and Bansal and Umar, (1998).

Kolar and Grewal (1989) studied on response of rice to potassium and reported that yield responded significantly to split application of 50 kg K ha^{-1} (1/2 at transplanting + 1/2 at active tillering). Split application of potassium at transplanting and panicle initiation and active tillering and panicle initiation also significantly increased yield. Application of 100 kg K at transplanting was as efficient as split application. potassium helped in increase panicle-bearing tillers and grain weight.

Ghosh and Mukhopadhyay (1996a) studied on critical limit of potassium in rice plant in Belar and Bankati series of West Bengal and reported that the average response to added potassium in deficient potassium status soils of Belar was 4.1, 12.1 and 6.4 per cent, while for Bankati soils was 10.0, 18.6 and 15.4 per cent at 20, 40, 60 mg K_2O kg^{-1} soil rates, respectively.

Prasad and Chauhan (2000) studied the rice response to rate and time of application of potassium in an upland ecosystem and reported that higher yield in rice was due to greater response of potassium through split application at appropriate growth stages over its conventional basal application.

Singh (2004) studied the response of rice varieties to potassium levels in an acidic peat soil of Manipur valley. The potassium content and uptake by rice grain and straw increased significantly with successive increase in potassium levels.

2.6 Soil potassium release capacity.

Potassium releasing power of soil was the sum of non-exchangeable potassium converted in to exchangeable form and exchangeable in to water soluble form.

Srinivasarao *et al.* (1997) studied the effect of acid strength on potassium release in shrink–swell soils of Madhya Pradesh and observed that increase in potassium release as the strength of acid increased, which indicated that the potassium release in shrink–swell soils having higher clay content and smectite dominance requires higher strength in the form of H^+ ions to replace K^+ from clay complex.

Srinivasarao *et al.* (1999) reported that continuous cropping for 20 years reduced the potassium release rates significantly and stated that many plants feed on non-exchangeable source of potassium, particularly the monocots. Therefore, current interest in potassium fertility of soils has switched from simple measurement of the amounts of exchangeable or non-exchangeable potassium to determination of the rate at which K^+ was supplied from these forms during the crop growth.

Srinivasarao *et al.,* (2006) studied among soil types, Alfisols at Bangalore and Anantapur, Vertisols at Akola showed lower potassium release parameters. Soils under lower rainfall area (<500 mm) showed higher release of potassium. Clay and CEC showed positive correlation with potassium supplying parameters of soils in most of the soils, while pH showed mainly positive relation potassium release in Alfisols and Inceptisols.

Subhash Chand and Ali (2011) studied the potassium releasing capacity in some soils of Anantnag district of Kashmir and resulted that significant correlations among different forms of potassium in Anantnag soils indicate the various potassium pools (exchangeable=non-exchangeable) for proper potassium fertilizer management.

2.7 Effect of potassium on plant nutrients concentration.

Brar and Singh (1995) studied on comparison of potassium status of Gurdaspur and Naura (*Typic Haplustalf*) soils of Punjab and reported that the potassium application increased the potassium concentration of plants at 45 days growth and in straw at maturity. However, the potassium concentration in seeds were almost same in control and K applied plants.

Fageria (2004) studied on dry matter yield and nutrient uptake by lowland rice at different growth stages and reported that concentrations of N, P, K, Ca, Mg, Zn, Mn, Fe and B significantly decreased with the advancement of plant age.

However, uptake of these nutrients was having significant quadratic increase with increasing plant age.

Uddin *et al.* (2012) studied the response of rice to split application of potassium in old Brahmaputra flood plain soil. The highest (0.82 %) and the lowest (0.53 %) N concentration in straw was recorded from T_9 and T_1, respectively. The highest P concentration (0.16 %) was noted with T_3, T_8 and T_9 and the lowest (0.11 %) with T_4. The uptake of these nutrients was highest in T_5 and lowest in T_1. (The treatments were: T_1=control, T_3=NPSZn+K25+K25,T_4=NPSZn+K75,T_5=NPSZn+K37.5+K37.5, T_8=NPSZn+K125, T_9=NPSZn+K62.5+K62.5).

Fageria and Knupp (2013) studied the upland rice phenology and nutrient uptake in tropical climate and reported that concentrations of N, K, Ca, Mg, Fe and Mn increased significantly and quadratically with plant age, whereas, P, Cu and Zn decreased quadratically with increasing plant age. Uptake of macro and micronutrients increased significantly in quadratic fashion with increasing plant age.

2.8 Effect of potassium on plant nutrients uptake.

Ramnathan and Krishnamoorthy (1982) studied on potassium releasing power *vis-a-vis* potassium supplying power of soils and reported that the results of the cumulative potassium uptake indicated almost the same trend as that of the cumulative dry matter yield as could be expected on account of their close relationship. The sample 24 was superior to other soils and contributed for the highest potassium uptake. The lowest potassium uptake was registered by sample 8, a highly depleted soil, which also registered the least cumulative potassium release value.

Pati Ram and Prasad (1983) studied the potassium supplying power of soils from the East Khasi hills of Meghalaya and reported that uptake of potassium by the first crop of maize varied from 54.6 to 189.1 mg pot^{-1} and the total potassium removed by all the five crops ranged from 175.1 to 468.2 mg pot^{-1}.

Bandyopadhyay and Goswami (1985) studied the potassium activity ratio and potassium uptake in three major soils of India and reported that the usefulness of potassium activity ratio (KAR) in soil solution in predicting the crop response to potassium under varying levels of potassium, Ca and Mg was studied for alluvial, black and laterite soils. KAR had a close relationship with potassium absorption by wheat in the absence of Ca and Mg were added at constant level of potassium to vary the KAR.

Chamuah and Dey (1987) studied the root cation exchange capacity in relation to nutrient uptake of rice and reported that the higher content of total cations in plant tops appear to be due to higher root CEC.

Panda and Panda (1993) Studied on evaluation of some potassium soil tests for rice in a *Fluventic Ustochrept* and reported that with variation in soil potassium fertility, marked variations were recorded for potassium uptake values (144 to 494 mg pot^{-1}). The corresponding relative potassium uptake values ranged from 25.9 to 104.9.

Singh *et al.* (2000) studied on soil test methods and critical limits of potassium for rice grown on *Typic Ustochrepts* and reported that the potassium uptake by the crop ranged from 158 to 485 mg pot^{-1}.

Md. Baque *et al.* (2006) studied on effects of fertilizer potassium on growth, yield and nutrient uptake of wheat (*Triticum aestivum*) under water stress conditions and reported that the uptake of N, P and K was lowered by the water stress. Consequently, most of the yield contributing characters as well as grain yield was reduced substantially. Higher levels of potassium improved the dry matter production of different plant parts. Yield and yield contributing characters of wheat were also improved due to high level of potassium application irrespective of the levels of soil moisture. Uptake of N, P and K was also enhanced with the increasing levels of potassium especially under water stress conditions. It was concluded that application of high level of potassium might mitigate the deleterious effects of water stress.

2.9 Correlation of potassium with plant nutrients uptake.

Very few K x P interaction studies have been reported perhaps due to lack of evidence for a K x P interaction in plant metabolism except for maintaining ionic balance (Adams, 1980).

Gupta (1986) studied the synergistic effects occurred when both K and Fe were applied resulting in increased rice yields as well as K and Fe uptake. Generally, application of K increased Cu concentration in plants when crops were well supplied with phosphorus (Wadington, 1972).

Umar *et al.* (1986) studied the response of rice to applied P was more or less uniform at all levels of applied N, but its response to potassium application increased when both N and P were applied. Crops with high requirement of potassium, such as maize, rice, often show strong N x K interaction (Singh, 1992).

Koria *et al.* (1989) reported significant and positive correlations of water soluble, exchangeable and non-exchangeable potassium fractions with EC whereas total potassium was correlated with organic carbon.

Mishra and Srivastava (1991) studied some red soil profile of Garhwal Himalayas and indicated that water soluble, exchangeable and available soil potassium had positive correlation with organic carbon and EC. Among different potassium forms, water soluble and exchangeable potassium were positively correlated with pH.

Vinay Singh *et al.,* (1992) studied on pea crop and reported that the application of K and Zn significantly increased their content and uptake. However, application of potassium alone decreased Zn concentration and increased its uptake. The uptake of potassium also increased by application of low levels of Zn. The K : Zn ratio increased with potassium and decreased with Zn addition.

3. MATERIAL AND METHODS

A pot culture experiment was conducted in wire house of Division of Soil Science and Agricultural Chemistry, College of Agriculture, Kolhapur during *kharif* season 2012 to evaluate the critical limits of potassium in soil and plant for upland paddy grown on shrink-swell soils. The material and standard methods employed in the present investigation are as under.

3.1 MATERIAL:-

3.1.1 Location of experimental site:-

College of Agriculture, Kolhapur is located near National Highway No.4, Kolhapur-Kagal road and about 5 km South-East from Kolhapur city. The location of the campus is between $16^{0}42'$ N latitude and between $74^{0}14'$ E longitude. It's elevation is 548 m above the mean sea-level.

3.1.2 Climate and weather:-

The College of Agriculture, Kolhapur comes under the Sub-montane Zone, with annual rainfall ranging from 700 to 2500 mm. The average annual rainfall is 1057 mm, out of which 80 per cent rain receives from south west monsoon in the month of June to September, while rest of the rain in the month of October and November from North West monsoon.

3.1.3 Soil samples:-

The soils used for filling the earthen pots with low, medium and high potassium status were collected from 18 different locations of College of Agriculture, Kolhapur Farm. The collected soils of different potassium status were dried in shade and sieved through 2 mm sieve. The sieved soils were used for filling the earthen pots and determination of available potassium. Then the soils were categorized into low, medium and high in respect of its available 'K' content. Out of 18 locations, soil samples from six locations were in the category of low available potassium content (<125 kg K_2O ha^{-1}), Six were from medium available potassium content (125-250 kg K_2O ha^{-1}) and six in high available potassium content (>250 kg K_2O ha^{-1}).

Table 1. Locations of soils and soil available potassium.

Sr. No.	Locations of soils	Survey No.	Symbol for location	Soil available K kg ha^{-1}
1	Agronomy Farm	343B/25B	L_1	78.40
2	Dairy Farm	360/29	L_2	89.60
3	Agronomy Farm	343B/26A	L_3	100.80
4	Horticulture Farm	368/58	L_4	100.80
5	Agronomy Farm	343B/25B	L_5	100.80
6	Dairy Farm	360/30	L_6	100.80
7	Horticulture Farm	368/67	M_1	145.60
8	Agronomy Farm	343B/26A	M_2	145.60
9	Horticulture Farm	368/65	M_3	156.80
10	Horticulture Farm	365/51	M_4	190.40
11	Agronomy Farm	358A/9C	M_5	190.40
12	Horticulture Farm	350/58	M_6	201.60
13	Horticulture Farm	368/65A	H_1	268.80
14	Horticulture Farm	368/65B	H_2	268.80
15	Horticulture Farm	368/67	H_3	280.00
16	Agronomy Farm	358A/9A	H_4	336.00
17	Agronomy Farm	358A/5A	H_5	336.00
18	Agronomy Farm	358A/5E	H_6	358.40

3.1.4 Selection of crop:-

The paddy crop variety Bhogawati was selected as a test crop during *kharif* season 2012.

3.1.5 Experimental layout:-

The present investigation was carried out in Factorial Completely Randomized Design. Treatments comprises two levels of potassium (0 and 50 kg K_2O ha^{-1}) through source of Muriate of potash (MOP) and were replicated twice.

3.1.6 Seeds:-

Genetically pure seeds of paddy cv. Bhogawati were obtained from the Farm Superintendent, Agronomy Farm, College of Agriculture Kolhapur.

3.1.7 Fertilizers:-

Fertilizers purchased by Farm Superintendent, Agronomy Farm, College of Agriculture, Kolhapur were used and the nutrient content of these fertilizers were as follows (Table 2). Macronutrients N, P and K were applied through straight fertilizers *viz.* urea, single superphosphate and muriate of potash, respectively.

Table 2. Details of fertilizers

Sr. No.	Name of fertilizer	Nutrient content (%)		
		N	P_2O_5	K_2O
1.	Urea	46	_	_
2.	Single super phosphate (SSP)	_	16	_
3.	Muriate of potash (MOP)	_	_	60

3.1.8 Earthen pots:-

Earthen pots of 10 kg capacity with 26.2 cm height and outer diameter of 52 cm at bottom and 98 cm at top were used for experimental purpose.

3.1.9 Polythene sheet:-

White polythene sheets of 1 mm thickness were used for lining the pots. The sheet was cut into pieces of 80 cm x 80 cm size and after lining the pots, extra paper remaining outside the pot was cut off.

3.1.10 Pest management:-

Hand picking method was used as mechanical control against the Rice Butterfly attack.

3.1.11 Water used for irrigation:-

Deionized water was used for irrigation throughout the experiment. Field capacity of soil was determined and pots were irrigated to maintain moisture at field capacity.

3.1.12 Wire house:-

The experiment was carried out in the wire house of the Division of Soil Science and Agricultural Chemistry, College of Agriculture, Kolhapur. Pots were arranged on platforms and arrangement were made to protect the pots from rainwater.

3.1.13 Chemicals:-

The chemicals used for analytical work were of high purity (analytical/guaranteed reagent grades).

3.1.14 Experimental details:-

Sr. No.	Particulars	*Kharif* 2012
1	Crop and variety	Upland Paddy, Bhogawati
2	Location	Wire house, Division of Soil Science and Agril. Chemistry, College of Agriculture, Kolhapur.
3	Experimental design	Factorial Completely Randomized Design (FCRD)
4	Potassium status and Treatments	a) Available Potassium status-3 (Low, Medium and High) b) Levels of K_2O – 2 (0 Kg K_2O ha^{-1} = absolute control and 50 Kg K_2O ha^{-1} = Optimum level)
5	Replications	2
6	Weight of experimental soil per pot	10 kg (2 mm sieved)
7	Seed rate	9 seeds pot^{-1}
8	Preparation of pots for experimentation	10th May 2012
9	Application of fertilizers	19th June 2012
10	Sowing of paddy seeds	20th June 2012
11	Harvesting (at 100 per cent flowering)	8th October 2012

3.2 METHODS:-

3.2.1 Preparation of soil samples:-

The collected surface soil samples (0-15 cm) were air dried. Out of the bulk samples collected, representative sample of 1 kg was obtained by quartering technique. Each sample was pounded with the help of a wooden mortar and pestle, sieved and stored in cotton bags and used for analysis.

The remaining bulk samples were pounded, passed through 2 mm sieve and were used for conducting pot culture experiment.

3.2.2 Filling of pots:-

The pots were filled with 10 kg of soil and moisture was maintained to field capacity with deionized water.

The experiment was conducted in Factorial Completely Randomized Design using eighteen samples with two treatments which replicated twice. Therefore, in all (18 x 2 x 2) 72 pots were filled with soil as per treatments.

Details of treatments are as below:-

Treatment symbol	Treatment details
K_0	0 kg K_2O ha^{-1} (Control)
K_{50}	50 kg K_2O ha^{-1} (Optimum dose)

3.2.3 Fertilizers application:-

The recommended dose of N, P and K for paddy (100:50:50 N: P_2O_5: K_2O kg ha^{-1}) was calculated on per ten kilogram soil basis and two levels of potash (0 and 50 kg K_2O ha^{-1}) were taken for experimental purpose. All fertilizers quantity including potash fertilizer were doubled in pot culture experiment.

3.2.4 Analysis of soil:-

The collected soil samples were analyzed for physico-chemical properties by using standard methods as given in Table 3.

Table 3. Methods used for soil analysis:-

Sr. No.	Parameters	Methods	References
A.	**Physical properties:-**		
1.	Soil Texture	International Pipette	Piper (1966)
B.	**Chemical properties:-**		
1.	pH (1:2.5 Soil : Water)	Potentiometric	Jackson (1973)
2.	EC (1:2.5 Soil : Water)	Conductometric	Jackson (1973)
3.	Calcium Carbonate	Rapid Titration	Piper (1966)
4.	Organic Carbon	Walkely-Black	Jackson (1973)
5.	Available Nitrogen	Alkaline Permagnate	Subbiah and Asija (1956)
6.	Available Phosphorus	0.5 *M* $NaHCO_3$ pH 8.5	Watanabe and Olsen (1965)
7.	Available Potassium	*1 N* Ammonium Acetate (pH – 7.0)	Knudsen and Peterson (1982)
8.	Available Micronutrients (Fe, Zn, Mn & Cu)	Atomic Absorption Spectrophotometry	Lindsay and Norvell (1978)
9.	Calcium and Magnesium	EDTA Titration	Jackson (1973)

3.2.5 Methods used for plant analysis:-

The analysis of powdered plant samples were carried out by using standard methods as given below.

Table 4. Methods used for plant analysis:-

Sr. No.	Parameters	Methods	Reference
1.	Total N	Micro-kjeldhal (Diacid Digestion)	Parkinson and Allen (1975)
2.	Total P	Vandomolybdate Yellow colour in Nitric Acid System (Triacid Digestion)	Jackson (1973)
3.	Total K	Flame Photometry (Triacid Digestion)	Chapman and Pratt (1973)
4.	Micronutrients (Fe, Mn, Zn & Cu)	Atomic Absorption Spectrophotometry	Zoroski and Burau (1977)

3.2.6 Sowing of seeds:-

Sowing of paddy seeds was done on 20th June, 2012. The seeds were treated with Azotobacter and PSB for healthy growth. Initially 6 seeds of rice per hill (3 hills) were dibbled in each pot. After germination, thinning was done and 3 healthy seedlings were kept per hill. Total 9 plants were maintained per pot.

3.2.7 Growing of plants:-

After sowing, pots were irrigated as per requirement. Plants were grown up to 100 per cent flowering stage. During the growth period all the interculturing operations were carried out as under.

3.2.7.1 Watering:-

Watering with deionized water was done and continued up to the flowering stage to maintain the soil at field capacity.

3.2.7.2 Thinning:-

Ten days after sowing i.e. on 30th June 2012, thinning was done and only nine healthy seedlings were kept in each pot.

3.2.7.3 Weeding:-

Timely weeding was done manually without disturbing the crop so as to keep all pots weed free.

3.2.7.4 Plant protection:-

Spraying of copper oxychloride and streptocycline was done to control the Blast and Bacterial blight of paddy.

3.2.8 Observations during plant growth:-

The observations for number of tillers were recorded at tillering stage. After 110 DAS the observations for plant height (cm) were recorded from the soil surface level in the pot to the tip of the top leaves. The dry matter yield (g pot^{-1}) was recorded after harvest (100 per cent flowering) of paddy crop.

3.2.9 Harvesting:-

The rice plants were harvested at 110 DAS (at 100 per cent flowering stage) i.e. on 8th October, 2012. The plants were harvested with utmost care and labeled them.

3.2.10 Preparation of plant samples for analysis:-

After harvesting plant samples were washed with distilled water. The shoot samples were air dried under shade for 5 days. After air drying samples were dried in oven at 60^{0}C ± 2^{0}C temperature by putting them into paper bags till constant weight. After oven drying the dry matter weight of samples were recorded.

Plant samples were ground in grinding mill to pass through 2 mm sieve. The powdered samples were stored in airtight butter paper bags and used for analysis of N, P, K and hand crushed samples were used for micronutrients (Fe, Mn, Zn and Cu) analysis.

3.2.11 Plant analysis:-

The processed plant samples were digested in diacid mixture (H_2SO_4: 30% H_2O_2) for nitrogen content. The triacid mixture (HNO_3: H_2SO_4: $HClO_4$) was used to digest the plant samples for estimation of phosphorous, potassium and micronutrients. The standard analytical methods were used for analysis given in Table 4.

3.3 Determination of critical limits:-

The critical level of potassium for upland paddy crop and for soil were determined by using standard procedure as suggested by Cate and Nelson (1965 and 1971) by graphical and statistical methods, respectively.

3.3.1 Establishment of critical limit of potassium by graphical method:

1. The scatter diagram of percentage yield (Y-axis) v/s. soil test value (X-axis) were plotted on arithmetic paper. The range in values on the Y-axis will always be 0 to 100 per cent, whereas the range for value on the X-axis was varying with the soil test procedure, the particular soil studied and the nutrient involved.

2. A piece of clear plastic having roughly one and one-half the dimension of the graph was cut out for use as an overlay. A pair of intersecting perpendicular lines are drawn on the overlay with black India ink in such a way that it was divided into four

sectors having area of roughly the same relative size. The signs of these quadrants were then labeled with black India ink.

3. The overlay was moved about horizontally and vertically on the graph always with the two lines parallel to the two axes on the graph, until the points in the negative quadrants were at a minimum.

4. The position of the lines on the overlay with respect to the axes of the graph was transferred to the graph by making marks on the edges of the graph. The two intersecting lines were then drawn lightly on the graph with pencil. The point where the vertical line crosses the X-axis was defined as the critical soil test level.

3.3.2 Establishment of critical limit of potassium by statistical method:

The steps followed for calculation of critical level of potassium by statistical approach as suggested by Cate and Nelson (1971) were as follows.

1) The initial soil test values of potassium were arranged in ascending order.
2) The per cent dry matter yield was written against each soil test potassium value.
3) The correction factor (C.F.) and total corrected sum of squares (T.C.S.S.) were calculated from per cent dry matter yield by using following formulae.

i) $$\text{C.F.} = \frac{(\Sigma\ Y)^2}{n} = \frac{\Sigma\,(Y_1 + Y_2 + Y_3 + \ldots\ldots Y_n)^2}{n}$$

ii) $$\text{T.C.S.S.} = \Sigma\ Yi^2 - \text{C. F.}$$

$$= \Sigma \ (Y_1 + Y_2 + Y_3 + \ldots\ldots.Y_n)^2 - C.F.$$

Where,

Y= per cent dry matter yield

n = total number of observations

4) The data were grouped into two groups i.e. if the total number of observations are 'n' then data was grouped as (p, n-p), (p + 1, n-P+1) e.g. if n = 15 then the data is grouped as (2, 13) (3,12) .... (13, 2)

5) A table with following columns were prepared

i) Last value of soil available nutrient.

ii) Plant available K included in population 1st

i.e. $= \frac{P_1 + P_2 \ldots\ldots\ldots P_n}{P}$

iii) Combine sum of square of deviation from mean of population 1st i.e. C.S.S.I.

Here total of all values of population 1st was made

C.S.S.I. $= \Sigma \ P_1^2 + P_2^2 \ldots\ldots.+ Pn^2 - \ \Sigma \left(\frac{P_1 + \ \ldots\ldots\ldots Pn}{n} \right)$

iv) If Kn was the number of observations in population, IInd then mean relative yield in population IInd

$$= \frac{K_1 + K_2 + \ldots\ldots. + K_n}{n}$$

v) Combined sum of squares of deviation from mean of population IInd (CSSII). Here total of all values of population IInd was made i.e. $(K_1 + K_2 + \ldots\ldots. + Kn)$

C.S.S.I. $= \Sigma \ K_1^2 + K_2^{2+} \ldots\ldots.+ Kn^2 \ - \ \Sigma \left(\frac{K_1 + \ \ldots\ldots\ldots Kn}{n} \right)^2$

vi) Postulated critical level (split between the two population) i.e. P.C.L. was calculated as

$$PCL = \frac{\text{last value in I}^{st}\text{ population + value in II}^{nd}\text{ population}}{2}$$

vii) $$R^2 = \frac{TCSS - CSSI - CSSII}{TCSS}$$

The concentration having highest R^2 is the critical concentration.

The critical level of Potassium in soil and plant were determined by following statistical approach as suggested by Cate and Nelson (1971).

4. RESULTS AND DISCUSSION

A pot culture experiment was conducted in wire house at the Division of Soil Science and Agricultural Chemistry, College of Agriculture, Kolhapur during *kharif* season 2012. The experimental results are presented and discussed under the appropriate heading in this chapter.

4.1 Initial soil analysis of collected soil samples for pot culture experiment.

4.2 Effect of potassium application on number of tillers per pot, height (cm) and dry matter yield (g pot^{-1}) of paddy plant grown on low, medium and high potassium status soils.

4.3 Effect of potassium application on concentration and uptake of nutrients of paddy plant grown on low, medium and high potassium status soils

4.4 Establishment of critical limits of potassium in soil and plant by graphical method.

4.5 Establishment of critical limits of potassium in soil and plant by statistical method.

4.6 Correlation coefficients between initial soil chemical properties and nutrients uptake by upland paddy.

4.1 Initial soil analysis of collected soil samples for pot culture experiment.

The 18 soil samples were collected from 18 different locations of Agriculture College Farm, Kolhapur and analyzed for the soil properties such as pH, EC, soil texture, calcium carbonate, organic carbon, available nitrogen, available phosphorus, available potassium, exchangeable calcium, magnesium and available micronutrients *viz.* iron, manganese, zinc and copper and the data are presented in Table 5.

The results revealed that the pH of experimental soil ranged from 6.80 to 8.20. EC ranged from 0.12 to 0.35 dS m^{-1}. The sand content ranged from 32.50 to 65.10, silt from 6.70 to 38.70 and clay from 15.00 to 38.20 per cent with textural class from sandy clay loam to clay. The $CaCO_3$ content of the soils ranged from 1.55 to 7.95 per cent. Organic carbon content ranged from 0.68 to 1.14 per cent. The available N ranged from 150.53 to 250.88 kg ha^{-1}. The available P ranged from 11.20 to 32.94 kg ha^{-1}. The available potassium ranged from 78.40 to 358.40 kg ha^{-1}. The six soil samples were low in available potassium (<125 kg K_2O ha^{-1}), six soil samples were medium in available potassium (125-250 kg K_2O ha^{-1}) and six soil samples were high in available potassium (>250 kg K_2O ha^{-1}). The exchangeable calcium and magnesium content ranged from 21.80 to 36.80 and 6.20 to 15.90 me 100 g^{-1} of soil, respectively. The micronutrients content ranges of soil *viz*. Fe 1.03 to 2.46 ppm, Mn 1.60 to 4.91 ppm, Zn 0.33 to 0.88 ppm and Cu 1.62 to 3.69 ppm.

The above results indicated that the soils were neutral to alkaline in reaction, low in electrical conductivity, moderately high to very high in organic carbon, slightly calcareous to calcareous, low in available nitrogen, low to high in available phosphorus and very low to very high in potassium content. The values for chemical properties were comparable to those reported by Borate (2010) and for physical properties it was comparable to values reported by Pathak (2011).

4.2 Effect of potassium application on number of tillers per pot, height (cm) and dry matter yield (g pot^{-1}) of paddy plant grown on low, medium and high potassium status soils.

The data in respect to number of tillers per pot, height (cm) and dry matter yield (g pot^{-1}) of paddy plant at 100 per cent flowering grown on low, medium and high potassium status soils as influenced by potassium application with K_0 and K_{50} are presented in Table 6 and depicted in Fig. 1 and 2.

4.2.1 Number of tillers per pot of paddy plant

The number of tillers per pot of paddy plant reported in Table 6 revealed that the significantly highest number of tillers per pot were recorded in high potassium status soils (37.37) as compared to medium (34.33) and low (31.29). The number of tillers per pot of paddy plant at 100 per cent flowering were increased significantly due to application of potassium 50 kg K_2O ha^{-1} (37.11) over control (31.55). The interaction effect between potassium status (low, medium and high) and treatment (K_0 and K_{50}) was non-significant in respect of number of tillers.

The maximum number of tillers per pot were observed in application of potassium K_{50} as compared to control K_0, this increase may be due to availability of nutrients (N, P and K) at initial stage of the crop growth and its higher uptake by the plant.

These results are in agreement with those reported by Singh (2004) in paddy plant.

4.2.2 Height of paddy plant

The results reported in Table 6 indicated that the significantly highest plant height was recorded in high potassium status soils (64.98 cm) as compared to medium (62.46 cm) and low (60.44 cm). The height of paddy plant at 100 per cent flowering was increased significantly due to application of potassium 50 kg K_2O ha^{-1} (66.31 cm) over control (58.94 cm). The interaction effect between potassium status (low, medium and high) and treatment (K_0 and K_{50}) was non-significant in respect of plant height.

The maximum plant height was observed in application of potassium K_{50} as compared to control K_0, this increase may be due to availability of nutrients (N, P and K) at initial stage of the crop growth and its higher uptake by the plant. The increase in plant height due to increase in cell division and cell elongation by utilization of applied nitrogen and its utilization in protein synthesis and increased level of auxin and gibberellin activity.

The results are in agreement with those reported by Singh *et al.* (2000) in paddy plant.

4.2.3 Dry matter yield of paddy plant

The results reported in Table 6 revealed that the significantly highest dry matter yield (g pot^{-1}) was found in high potassium status soils (45.06 g pot^{-1}) as compared to medium (43.34 g pot^{-1}) and low (38.00 g pot^{-1}). The dry matter accumulation (g pot^{-1}) of paddy plant at 100 per cent flowering was found to increase significantly due to application of 50 kg k_2O ha^{-1} (49.77 g pot^{-1}) over control (34.49 g pot^{-1}). The interaction effect between potassium status (low, medium and high) and treatment (K_0 and K_{50}) was non-significant in respect of dry matter yield of paddy plant.

The increase in vegetative growth obtained with the application of higher doses of N, P and K would result in higher dry matter yield of the plants. Nutrient status would have helped to synthesis and assimilate more nutrients which could have converted to synthesis of photo assimilates.

The results are in confirmative with those reported by Zia et al. (1987), Panda and Panda (1993) and Ghosh and Mukhopadhyay (1996a) in paddy plant.

Table 6. Effect of potassium application on number of tillers per pot, height (cm) and dry matter yield (g pot^{-1}) of paddy plant grown on low, medium and high potassium status soils.

	Number of tillers (per pot)	Plant height (Cm)	Dry matter yield (g pot^{-1})
A. Potassium status (Ps)			
Low	31.29	60.44	38.00
Medium	34.33	62.46	43.34
High	37.37	64.98	45.06
SE ±	0.517	0.237	0.392
CD @ 5%	1.460	0.669	1.106
B. Treatment (T)			
K_0	31.55	58.94	34.49
K_{50}	37.11	66.31	49.77
SE ±	0.422	0.193	0.320
CD @ 5%	1.192	0.546	0.903
Interaction(Ps X T)			
SE ±	0.731	0.335	0.554
CD @ 5%	NS	NS	NS

4.3 Effect of potassium application on concentration and uptake of nutrient of paddy plant grown on low, medium and high potassium status soils.

The data resulted in respect to concentration (per cent) macronutrients uptake (g pot^{-1}) and micronutrients uptake (mg pot^{-1}) of paddy plant at 100 per cent flowering grown on low, medium and high potassium status soils as influenced by potassium application with K_0 and K_{50} are reported in Table 7, 8, 9 and macronutrients uptake depicted in Fig. 3 and 4.

4.3.1 Nitrogen concentration in paddy plant

The nitrogen concentration in paddy plant reported in Table 7 revealed that the significantly highest nitrogen concentration was recorded in high potassium status soils (1.58 per cent) as compared to medium (1.41 per cent) and low potassium status (1.11 per cent). The nitrogen concentration in paddy plant at 100 per cent flowering was significantly influenced due to application of potassium K_{50} (1.61 per cent) over control K_0 (1.13 per cent). The interaction effect between potassium status (low, medium and high) and treatment (K_0 and K_{50}) was non-significant in respect of nitrogen concentration in paddy plant.

The nitrogen concentration in the plant showed a gradual increase with the progressive growth and development of the crop up to flowering.

The results are following similar trend with those obtained previously by Surekha *et al.* (2003). in paddy plant.

4.3.2 Phosphorus concentration in paddy plant

The data presented in Table 7 indicated that the significantly highest phosphorus concentration was observed in high potassium status soils (0.12 per cent) over medium (0.09 per cent) and low (0.05 per cent) potassium status soils. The phosphorus concentration in paddy plant at 100 per cent flowering was significantly higher due to application of 50 kg k_2O ha^{-1} (0.10 per cent) over control (0.08 per cent). The interaction effect between potassium status (low, medium and high) and treatment (K_0 and K_{50}) was non-significant in respect of phosphorus concentration in paddy plant.

The increase in phosphorus concentration could possibly due to the production of enzymes complexes that solubilize the unavailable phosphorus and makes it available to plant.

Similar, findings were reported by Singh *et al.* (1987) and Uddin *et al.* (2012) in paddy plant.

4.3.3 Potassium concentration in paddy plant

The results presented in Table 7 revealed that the significantly highest potassium concentration was recorded in high potassium status soils (1.38 per cent) as compared to medium (1.16 per cent) and low (0.86 per cent). The potassium concentration in paddy plant at 100 per cent flowering was significantly influenced due to application of potassium K_{50} (1.24 per cent) over control K_0 (1.02 per cent). The interaction effect between potassium status (low, medium and high) and treatment (K_0 and K_{50}) was non-significant in respect of potassium concentration in paddy plant.

The potassium concentration in paddy plant increased from vegetative growth to flowering. The reason might be that the treatments with inorganic fertilizers might have increased the CEC and exchangeable cations, which ultimately led to increased potassium absorption. These results are in confirmative with those reported by Singh *et al.* (1987), Zia *et al.* (1987), Ghosh and Mukhopadhyay (1996a) and Singh *et al.* (2000).

Table 7. Effect of potassium application on macronutrients concentration (%) in paddy plant grown on low, medium and high potassium status soils.

	Nutrients concentration (%)		
	N	**P**	**K**
A. Potassium status (Ps)			
Low	1.11	0.05	0.86
Medium	1.41	0.09	1.16
High	1.58	0.12	1.38
SE ±	0.028	0.003	0.026
CD @ 5%	0.080	0.008	0.074
B. Treatment (T)			
K_0	1.13	0.08	1.02
K_{50}	1.61	0.10	1.24
SE ±	0.023	0.002	0.021
CD @ 5%	0.066	0.006	0.060
Interaction(Ps X T)			
SE ±	0.040	0.004	0.037
CD @ 5%	NS	NS	NS

4.3.4 Nitrogen uptake by paddy plant

The nitrogen uptake by paddy plant reported in Table 8 resulted that the significantly highest nitrogen uptake was observed in high potassium status soils (0.73 g pot^{-1}) as compared to medium (0.63 g pot^{-1}) and low (0.44 g pot^{-1}). The nitrogen uptake by paddy plant at 100 per cent flowering was significantly increased due to application of 50 kg K_2O ha^{-1} (0.80 g pot^{-1}) over control (0.39 g pot^{-1}). The interaction effect between potassium status (low, medium and high) and treatment (K_0 and K_{50}) was significant in respect of nitrogen uptake by paddy plant at 100 per cent flowering.

The results are in corroborative with the findings of Kumbhar (1997).

4.3.5 Phosphorus uptake by paddy plant

The data presented in Table 8 indicated that the significantly highest phosphorus uptake was recorded in high potassium status soils (0.05 g pot^{-1}) over medium (0.04 g pot^{-1}) and low (0.02 g pot^{-1}). The phosphorus uptake by paddy plant at 100 per cent flowering was significantly influenced due to application of potassium K_{50} (0.05 g pot^{-1}) over control K_0 (0.02 g pot^{-1}). The interaction effect between potassium status (low, medium and high) and treatment (K_0 and K_{50}) was significant in respect of phosphorus uptake by paddy plant at 100 per cent flowering.

The results are in agreement with those reported by Kumbhar (1997) that the potassium application had increase P uptake by paddy plant.

4.3.6 Potassium uptake by paddy plant

The data reported in Table 8 indicated that the significantly highest potassium uptake was obtained in high potassium status soils (0.63 g pot^{-1}) as compared to medium (0.51 g pot^{-1}) and low potassium status (0.33 g pot^{-1}). The potassium uptake by paddy plant at 100 per cent flowering was significantly increased due to application of potassium K_{50} (0.62 g pot^{-1}) over control K_0 (0.35 g pot^{-1}). In case of interaction effect between potassium status (low, medium and high) and treatment (K_0 and K_{50}) was significant in respect of potassium uptake by paddy plant at 100 per cent flowering.

In respect of nutrient uptake, the results indicated that at higher dose of N, P, and K increased the total uptake and also the interaction effect between potassium status and treatment were observed. The nutrient uptake of paddy was continuous and reached the highest at flowering stage. In general, result indicated that the plant having high yield removed high N, P and K from soil.

Similarly, Ghosh and Mukhopadhyay (1996a), Singh et al. (2000) and Singh (2004) reported that application of potassium had increase K uptake.

Table 8. Effect of potassium application on macronutrients uptake (g pot^{-1}) by paddy plant grown on low, medium and high potassium status soils.

	Nutrients uptake (g pot^{-1})		
	N	**P**	**K**
A. Potassium status (Ps)			
Low	0.44	0.02	0.33
Medium	0.63	0.04	0.51
High	0.73	0.05	0.63
SE ±	0.015	0.001	0.012
CD @ 5%	0.042	0.004	0.035
B. Treatment (T)			
K_0	0.39	0.02	0.35
K_{50}	0.80	0.05	0.62
SE ±	0.012	0.001	0.010
CD @ 5%	0.034	0.003	0.029
Interaction (Ps X T)			
SE ±	0.021	0.002	0.018
CD @ 5%	0.059	0.006	0.050

4.3.7 Micronutrients uptake by paddy plant

The data presented in Table 9 indicated that the significantly highest Fe, Mn, Zn and Cu uptake by paddy plant at 100 per cent flowering were recorded in high potassium status soils (436.65, 47.50, 3.37 and 22.48 mg pot^{-1}, respectively) as compared to medium (334.97, 32.26, 2.23 and 13.33 mg pot^{-1}, respectively) and low (209.39, 21.08, 1.14 and 7.84 mg pot^{-1}, respectively). The Fe, Mn, Zn and Cu uptake by paddy plant were significantly influenced due to application of 50 kg K_2O ha^{-1} (448.85, 47.89, 3.32 and 20.28 mg pot^{-1}, respectively) over control (205.15, 19.34, 1.17 and 8.82 mg pot^{-1}, respectively).

The interaction effect between potassium status (low, medium and high) and treatment (K_0 and K_{50}) were significant in respect of Fe, Mn, Zn and Cu uptake by paddy plant at 100 per cent flowering.

Table 9. Effect of potassium application on micronutrients uptake (mg pot^{-1}) by upland paddy grown on low, medium and high potassium status soils.

	Micronutrients uptake (mg pot^{-1})			
	Fe	**Mn**	**Zn**	**Cu**
A. Potassium status (Ps)				
Low	209.39	21.08	1.14	7.84
Medium	334.97	32.26	2.23	13.33
High	436.65	47.50	3.37	22.48
SE ±	12.451	1.076	0.118	0.564
CD @ 5%	35.156	3.038	0.334	1.594
B. Treatment (T)				
K_0	205.15	19.34	1.17	8.82
K_{50}	448.85	47.89	3.32	20.28
SE ±	10.166	0.878	0.096	0.461
CD @ 5%	28.705	2.480	0.272	1.301
Interaction (Ps X T)				
SE ±	17.608	1.522	0.167	0.798
CD @ 5%	49.718	4.296	0.472	2.254

4.4 Establishment of critical limits of potassium in soil and plant by graphical method

The critical limits of potassium in soil and plant from the normal soils and plants were determined, which can be employed to forecast the need for potassium fertilization. In view of the discrepancies in soil test crop response data in calculating the fertilizer requirement, Cate and Nelson (1965) suggested the need for more adequate representation of the relationship between soil test values and Bray's per cent yield, which further developed into graphical method for establishing critical limits of potassium in soil and plant.

4.4.1 Critical limits of potassium in soil and plant

The data on soil available potassium, dry matter yield of paddy plant at 0 and 50 kg K_2O ha^{-1}, concentration of potassium in paddy plant and Bray's per cent yield are presented in Table 10.

In the graphical method as suggested by Cate and Nelson (1965) yield obtained in the experiment was converted into Bray's per cent yield and was calculated as follows.

$$\text{Bray's percent yield} = \frac{\text{Yield without potassium}}{\text{yield with optimum potassium}} \text{X100}$$

The soils selected for this study contained available potassium in the range of 78.40 to 358.40 kg ha^{-1}. The dry matter yield of paddy without potassium (K_0) and with potassium (K_{50}) ranged from 27.85 to 37.49 g pot^{-1} and 37.88 to 53.72 g pot^{-1}, respectively. The calculated Bray's per cent yield ranged from 67.84 to 73.52. After plotting the Bray's per cent yield v/s soil available potassium, the critical limits were determined.

Table 10. Effect of potassium application on dry matter yield and its corresponding Bray's per cent yield of upland paddy.

Sr. No.	Soil avail. K (kg ha^{-1})	Dry matter yield (g pot^{-1}) Potassium levels (kg ha^{-1})		Bray's per cent yield	Plant K (%)
		K_0	K_{50}		
1.	78.40	27.85	37.88	73.52	0.71
2.	89.60	31.25	45.98	67.96	0.93
3.	100.80	31.35	46.08	68.03	1.07
4.	100.80	33.90	49.78	68.09	1.02
5.	100.80	31.58	46.35	68.13	1.02
6.	100.80	30.80	43.19	71.31	1.04
7.	145.60	34.69	50.72	68.39	1.07
8.	145.60	34.45	49.62	69.42	1.32
9.	156.80	34.86	51.33	67.91	1.32
10.	190.40	35.13	51.78	67.84	1.34
11.	190.40	35.90	52.32	68.61	1.34
12.	201.60	36.47	52.86	68.99	1.41
13.	268.80	36.11	52.24	69.12	1.41
14.	268.80	36.85	52.32	70.43	1.41
15.	280.00	37.30	52.89	70.52	1.45
16.	336.00	37.56	53.57	70.11	1.49
17.	336.00	37.39	53.27	70.18	1.49
18.	358.40	37.49	53.72	69.78	1.53

A cross was placed over the data and moved until the upper left and lower right quadrant have a minimum number of points. The critical value was read from the X-axis where the vertical line intersects it. The established critical limits of potassium for soil and paddy plant were depicted in Fig. 5 and 6, respectively. Thus, according to graphical method, scatter diagram indicated 264.22 kg K ha^{-1} as critical limit of potassium in soil, while 1.39 per cent potassium as critical limit of potassium in paddy plant at 100 per cent flowering, below which the response to potassium application to soil may be expected in case of paddy crop.

4.5 Establishment of critical limits of potassium in soil and plant by statistical method

The soil test values were often divided into two or more classes for the purpose of making fertilizer recommendations. However, the basis for different classes such as low, medium and high potassium status were often subjective or arbitrary. In the graphical approach discussed previously the dividing line between two categories were drawn approximately and thus the subjectivity was involved in superimposing the vertical and horizontal lines on a scatter diagram. Therefore, in order to overcome this, a statistically sound method for setting class limits was suggested by Cate and Nelson (1971). A mathematical model has been developed for partitioning soil analysis correlation data into two sets i.e. responsive and non-responsive soils as per method suggested by Cate and Nelson (1971).

4.5.1 Critical limit of potassium in soil by statistical method

Soil test data obtained from the experiment on paddy crop was subjected to the statistical method for computing critical level of potassium in soil as suggested by Cate and Nelson (1971) which presented in Table 11.

The threshold value for soil available potassium can be isolated by considering the highest R^2 value with corresponding postulated critical value for paddy crop which can be identified as 268.80 kg K ha^{-1}. Thus, it showed that paddy crop grown on soils containing available potassium below the defined threshold value may respond to the applied potassium on shrink-swell soils (Vertisol) of Sub montane Zone.

Similar results were reported by Subba Rao and Reddy (2005) in which the critical limit of potassium for paddy crop was 120 mg K kg^{-1} in alluvial soils of Uttar Pradesh.

4.5.2 Critical limit of potassium in paddy plant by statistical method

Similar to soil test data, plant test data obtained from the experiment were subjected to the statistical approach for computing the critical level of potassium in paddy plant as suggested by Cate and Nelson (1971), and presented in Table 12.

The threshold value of plant potassium can be isolated by considering highest R^2 value with corresponding postulated critical value for paddy at 100 per cent flowering, which was identified as 1.41 per cent.

It was indicated that below this critical level of potassium in plant response of potassium application to paddy may be expected in case of paddy grown on shrink-swell soils.

Similar result was reported by Singh *et al.* (2000) in which the critical limit of paddy crop was 1.92 per cent at flowering stage.

4.6 Correlation coefficients between initial soil chemical properties and nutrients uptake by upland paddy

Correlation coefficients between initial soil chemical properties and nutrients uptake (without K) by paddy plant at 100 per cent flowering was worked out and reported in Table 13.

The soil pH was significantly positively correlated to plant uptake of N (0.612**), P (0.475*), K (0.505*), Fe (0.630**), Mn (0.567*), Zn (0.723**) and Cu (0.663**). The soil Electrical Conductivity, soil calcium carbonate and soil Zinc were positively correlated to all nutrients uptake by paddy plant. The soil organic carbon was significantly positively correlated with plant P (0.559*) and Mn (0.487*) uptake and positively correlated with plant N, K, Fe, Zn and Cu uptake. The soil Fe was negatively correlated to all nutrients uptake by paddy plant. The soil nitrogen was positively correlated to plant N, P, K and Zn uptake and negatively correlated to plant Fe, Mn and Cu uptake. The soil phosphorus was positively correlated to uptake of P, K and Mn, while significantly positively correlated to uptake of N (0.478*), Fe (0.511*), Zn (0.555*) and Cu (0.545*) by paddy plant.

The soil potassium was significantly positively correlated to plant N (0.947**), plant P (0.906**), plant K (0.925**), plant Fe (0.974**), plant Mn (0.875**), plant Zn (0.956**), plant Cu (0.985**) uptake i.e. all nutrients uptake by paddy plant. The exchangeable calcium was significantly positively correlated to all nutrients uptake by paddy plant. The exchangeable magnesium and soil Cu were significantly negatively correlated to all nutrients uptake by paddy plant. The soil Mn was negatively correlated to all nutrients uptake by paddy plant.

Table 5. Physico-chemical properties of the soils (Initial soil analysis)

Sr. No.	Survey No.	pH (1:2.5)	EC (dS m^{-1})	Partical size distribution (%)			Textural Class	$CaCO_3$ (%)	Organic Carbon (%)	Available nutrients (Kg ha^{-1})			Exch. cations (me 100 g^{-1} of soil)		Avail. Micronutrients (ppm)			
				Sand	Silt	Clay				N	P	K	Ca^{2+}	Mg^{2+}	Fe	Mn	Zn	Cu
1	343B/25B	7.10	0.24	60.10	18.50	21.40	Scl	2.15	0.93	206.98	17.92	78.40	29.80	13.80	1.16	2.62	0.45	3.69
2	360/29	7.20	0.23	58.20	9.50	32.30	Scl	1.55	1.05	175.62	13.44	89.60	25.00	12.60	1.77	3.60	0.82	2.84
3	343B/26A	6.80	0.13	47.20	20.60	32.20	Scl	2.25	0.83	225.79	15.68	100.80	29.60	15.90	1.47	3.13	0.51	3.10
4	343B/26C	6.90	0.12	58.10	16.20	25.70	Scl	1.85	0.68	206.98	17.02	100.80	26.00	13.40	2.46	1.90	0.42	3.64
5	368/58	7.00	0.28	63.90	21.10	15.00	Sl	2.20	1.07	235.20	20.16	100.80	27.60	13.00	1.58	2.93	0.52	3.11
6	360/30	7.50	0.35	59.80	22.10	18.10	Sl	1.65	0.89	244.61	11.20	100.80	23.40	12.80	1.68	2.74	0.65	1.84
7	368/67	6.90	0.17	65.10	12.40	22.50	Scl	1.75	1.14	247.74	12.32	145.60	29.60	13.20	1.52	1.67	0.40	2.92
8	343B/26A	6.80	0.16	56.30	11.20	32.50	Scl	2.35	0.98	213.25	23.52	145.60	29.80	8.00	1.08	1.37	0.72	3.34
9	368/65	7.40	0.15	58.20	25.10	16.70	Sl	2.45	1.05	247.74	17.92	156.80	30.60	9.50	1.37	1.60	0.34	3.26
10	365/51	6.80	0.19	63.20	12.30	24.50	Scl	1.75	0.99	250.88	20.16	190.40	21.80	7.60	1.34	2.98	1.15	3.01
11	358A/9C	8.00	0.22	62.40	19.00	18.60	Sl	1.75	1.05	175.62	15.68	190.40	29.60	10.00	1.23	3.21	0.54	2.35
12	350/58	7.10	0.19	55.10	6.70	38.20	Scl	2.40	1.13	219.52	21.28	201.60	36.80	9.00	1.08	4.91	0.35	2.57
13	368/65	7.20	0.18	40.00	25.70	34.30	Cl	7.95	1.14	241.47	21.28	268.80	32.80	8.80	1.57	1.41	0.69	2.61
14	368/65	7.30	0.12	59.10	9.50	31.40	Scl	6.75	0.98	222.66	13.44	268.80	30.20	6.40	1.25	4.01	0.57	2.54
15	368/67	7.10	0.28	64.30	19.30	16.40	Sl	7.25	1.02	213.25	14.56	280.00	36.80	13.60	1.03	3.69	0.33	3.13
16	358A/9A	7.90	0.21	38.10	38.70	23.20	L	2.00	1.13	150.53	15.68	336.00	30.20	6.20	1.47	2.10	0.78	1.62
17	358A/5A	8.20	0.32	32.50	34.10	33.40	Cl	1.65	0.98	219.52	29.12	336.00	28.00	9.00	1.34	1.24	0.74	1.98
18	358A/5E	8.10	0.33	57.20	11.10	31.70	Scl	2.35	1.05	250.88	32.94	358.40	35.80	8.40	1.50	1.61	0.88	1.82
	Range value	6.80-8.20	0.12-0.35	32.50-65.10	6.70-38.70	15.00-38.20		1.55-7.95	0.68-1.14	150.53-250.88	11.20-32.94	78.40-358.40	21.80-36.80	6.20-15.90	1.03-2.46	1.60-4.91	0.33-0.88	1.62-3.69

Table 11. Critical limit of soil potassium by statistical method (Cate and Nelson, 1971)

Sr. No.	Soil available K (Kg ha^{-1}) population-1	Bray's per cent yield	Last value in population-1	Mean Bray's per cent yield in population-1	Corrected SS of deviations from mean of population-1	Mean Bray's per cent yield in population-2	Corrected SS of deviations from mean of population-2	Postulated critical limit	R^2 for Postulated critical limit
1	78.40	73.52							
2	89.60	67.96	89.6	70.74	15.43	69.18	18.19	95.20	0.1145
3	100.80	68.03	100.8	69.84	20.32	69.25	16.80	100.80	0.0225
4	100.80	68.09	100.8	69.40	22.62	69.34	15.34	100.80	0.0003
5	100.80	68.13	100.8	69.15	23.92	69.43	13.76	100.80	0.0077
6	100.80	71.31	100.8	69.51	27.82	69.27	9.94	123.20	0.0057
7	145.60	68.39	145.6	69.35	28.89	69.35	9.08	145.60	0.0000
8	145.60	69.42	145.6	69.36	28.90	69.35	9.08	151.20	0.0000
9	156.80	67.91	156.8	69.20	30.76	69.51	6.78	173.60	0.0116
10	190.40	67.84	190.4	69.06	32.42	69.72	3.64	190.40	0.0505
11	190.40	68.61	190.4	69.02	32.60	69.88	2.24	196.00	0.0825
12	201.60	68.99	201.6	69.02	32.60	70.02	1.33	235.20	0.1066
13	268.80	69.12	268.8	69.02	32.61	70.20	0.34	**268.80**	**0.1323**
14	268.80	70.43	268.8	69.12	34.44	70.15	0.28	274.40	0.0857
15	280.00	70.52	280	69.22	36.26	70.02	0.09	308.00	0.0427
16	336.00	70.11	336	69.27	37.01	69.98	0.08	336.00	0.0234
17	336.00	70.18	336						
18	358.40	69.78	358.4						

Table 12. Critical limit of plant potassium by statistical method (Cate and Nelson, 1971)

Sr. No.	Plant K per cent population-1	Bray's per cent yield	Last value in population-1	Mean Bray's per cent yield in population-1	Corrected SS of deviations from mean of population-1	Mean Bray's per cent yield in population-2	Corrected SS of deviations from mean of population-2	Postulated critical limit	R^2 for Postulated critical limit
1	0.71	73.5							
2	0.93	67.9	0.93	70.74	15.43	69.18	18.65	0.98	0.1131
3	1.02	68.0	1.02	69.86	20.12	69.25	17.39	1.02	0.0240
4	1.02	68.1	1.02	69.43	22.36	69.33	16.04	1.03	0.0007
5	1.04	71.3	1.04	69.80	25.20	69.18	11.82	1.06	0.0366
6	1.07	68.0	1.07	69.51	27.82	69.27	10.39	1.07	0.0056
7	1.07	68.3	1.07	69.35	28.89	69.36	9.54	1.20	0.0000
8	1.32	69.4	1.32	69.36	28.90	69.35	9.53	1.32	0.0000
9	1.32	67.9	1.32	69.20	30.76	69.51	7.23	1.33	0.0114
10	1.34	67.6	1.34	69.04	33.02	69.75	3.18	1.34	0.0581
11	1.34	68.8	1.34	69.02	33.06	69.88	2.24	1.38	0.0815
12	1.41	68.9	1.41	69.02	33.06	70.02	1.33	1.41	0.1053
13	1.41	69.1	1.41	69.02	33.07	70.20	0.34	**1.41**	**0.1307**
14	1.41	70.4	1.41	69.12	34.90	70.15	0.28	1.43	0.0846
15	1.45	70.5	1.45	69.22	36.72	70.02	0.09	1.47	0.0422
16	1.49	70.1	1.49	69.27	37.46	69.98	0.08	1.49	0.0231
17	1.49	70.1	1.49						
18	1.53	69.7	1.53						

Table 13. Correlation coefficients between initial soil chemical properties and nutrients uptake (without K) by upland paddy at 100 per cent flowering.

Soil chemical properties / Plant nutrients uptake	pH	EC (dSm^{-1})	Organic Carbon (%)	$CaCO_3$ (%)	Available nutrients ($Kg\ ha^{-1}$)			Exch. Cations (me 100 g^{-1} of soil)		Micronutrients (ppm)			
					N	P	K	Ca^{2+}	Mg^{2+}	Fe	Mn	Zn	Cu
N (g pot^{-1})	0.612**	0.200	0.467	0.323	0.047	0.478*	0.947**	0.475*	-0.744**	-0.308	-0.157	0.255	-0.651**
P (g pot^{-1})	0.475*	0.104	0.559*	0.407	0.087	0.432	0.906**	0.582*	-0.726**	-0.463	-0.128	0.167	-0.517*
K (g pot^{-1})	0.505*	0.153	0.347	0.399	0.074	0.457	0.925**	0.524*	-0.630**	-0.264	-0.110	0.169	-0.595**
Fe (mg pot^{-1})	0.636**	0.271	0.392	0.333	-0.001	0.511*	0.974**	0.516*	-0.647**	-0.283	-0.136	0.266	-0.640**
Mn (mg pot^{-1})	0.567*	0.014	0.487*	0.260	-0.410	0.307	0.875**	0.477*	-0.695**	-0.328	-0.150	0.227	-0.552*
Zn (mg pot^{-1})	0.723**	0.409	0.409	0.311	0.010	0.555*	0.956**	0.507*	-0.594**	-0.332	-0.135	0.205	-0.663**
Cu (mg pot^{-1})	0.663**	0.275	0.370	0.321	-0.057	0.545*	0.985**	0.529*	-0.627**	-0.281	-0.162	0.254	-0.641**

** Significant at 1 per cent level of significance.
* Significant at 5 per cent level of significance.

5. SUMMARY AND CONCLUSIONS

5.1 Summary:-

A pot culture experiment was conducted during *Kharif* season 2012 in wire house of Division of Soil Science and Agricultural Chemistry, College of Agriculture, Kolhapur for assessing the critical limits of potassium in soil and plant for upland paddy (*Oryza sativa* L.) grown on shrink-swell soils having low, medium and high potassium status soils. The effect of potassium application at different levels (*viz.*, 0 and 50 kg K_2O ha^{-1}) on plant growth, dry matter yield, nutrient concentration, uptake of nutrients and correlation coefficients between initial soil chemical properties and nutrients uptake by paddy plant (without K) at 100 per cent flowering was studied. The salient features of the results obtained are summarized below.

1. The 18 soil samples were collected from eighteen different locations and used for the pot culture experiment. These soils were sandy clay loam to clay in texture, neutral to alkaline in reaction (pH between 6.8 to 8.2), safe in EC (ranged from 0.12 to 0.35 dSm^{-1}), slightly calcareous to calcareous (1.55 to 7.95 per cent), moderately high to very high organic carbon (0.68 to 1.14 per cent), low available N content (150.53 to 250.88 kg ha^{-1}), low to high in available P content (11.20 to 32.94 kg ha^{-1}), very low to very high in available potassium content (78.40 to 358.40 kg ha^{-1}), exchangeable calcium and magnesium content (21.80 to 36.80 and 6.2 to 15.9 me 100 g^{-1} of soil, respectively) and micronutrients content Fe (1.03-2.46 ppm), Mn (1.60-4.91 ppm), Zn (0.33-0.88 ppm), and Cu (1.62-3.69 ppm).

2. The number of tillers, plant height and dry matter yield were increased significantly due to application of potassium 50 kg K_2O ha^{-1} (37.11), (66.31 cm) and (49.77g pot^{-1}) over control (31.55), (58.94 cm) and (34.49 g pot^{-1}), respectively.
3. The N concentration and uptake of paddy crop at 100 per cent flowering was significantly increased due to application of potassium. N concentration ranged from 1.13 to 1.61 per cent and uptake ranged from 0.39 to 0.80 g pot^{-1}. The P concentration and uptake of paddy crop at 100 per cent flowering were significantly increased due to application of potassium. The P concentration ranged from 0.08 to 0.10 per cent and uptake ranged from 0.02 to 0.05 g pot^{-1}.
4. The potassium concentration and uptake of paddy crop at 100 per cent flowering were significantly increased due to application of potassium. The potassium concentration ranged from 1.02 to 1.24 per cent and uptake ranged from 0.35 to 0.62 g pot^{-1}.
5. The critical limit of potassium for soil was found 264.22 and 268.80 kg K ha^{-1}, respectively by graphical and statistical methods.
6. The critical limit of potassium in paddy plant at 100 per cent flowering was found 1.39 and 1.41 per cent, respectively by graphical and statistical methods.
7. Correlation coefficients between initial soil chemical properties and nutrients uptake without K showed that the soil potassium was significantly positively correlated with all nutrients uptake without K.

5.2 Conclusions:-

1) The critical limit for soil available potassium was found 264.22 kg K ha^{-1} by graphical method (Cate and Nelson, 1965) and 268.80 kg K ha^{-1} by statistical method (Cate and Nelson, 1971), respectively. The results suggesting that, if soil containing less than 268.80 kg K ha^{-1}, the crop would respond to application of potash fertilizers.

2) The critical limit for potassium in paddy plant at 100 per cent flowering was found 1.39 per cent by graphical method (Cate and Nelson, 1965) and 1.41 per cent by statistical method (Cate and Nelson, 1971), respectively. The results suggesting that, if potassium concentration in paddy plant is less than 1.41 per cent, the crop would respond to application of potash fertilizers.

3) The soil available potassium was significantly positively correlated with all nutrients uptake by paddy plant in case of without application of potassium.

4) The results of the present study are based on only one variety of paddy and low, medium and high potassium status soils, which needs to be confirmed by using other varieties at different locations, seasons and various potassium levels.

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*__Original not seen.__

7. VITA

Miss. Savita Ravindra Shinde

A candidate for the degree
of
MASTER OF SCIENCE (AGRICULTURE)

SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

2013

Title of Thesis	Evaluation of critical limits of potassium in soil and plant for upland paddy grown on shrink-swell soils.
Major field	Soil Science

Biographical information :

Personal	Born in Shewali, Tal. Sakri, Dist. Dhule on 22nd July, 1989. Daughter of Shri. Ravindra S. Shinde (Head Master, Chhatrapati Sambhaji High School, Shenpur, Tal. Sakri, Dist. Dhule.) and Sou. Alka R. Shinde.
Educational	Completed Secondary School Education in Chhatrapati Sambhaji High School, Shenpur, Tal. Sakri, Dist. Dhule. In 2005 with First class with Distinction.
	Higher Secondary education from S. G. Patil Arts, Commerce and Science College, Sakri. in 2007 with First class.
	Received B.Sc. (Agriculture) degree in First Class (7.65) from the College of Agriculture, Dhule (M. P. K. V., Rahuri) in 2011.
Address	At/post – Shikshak Colony, Kasare, Tal. Sakri, Dist. Dhule. PIN 424310.
E-mail	shindesavita22@gmail.com

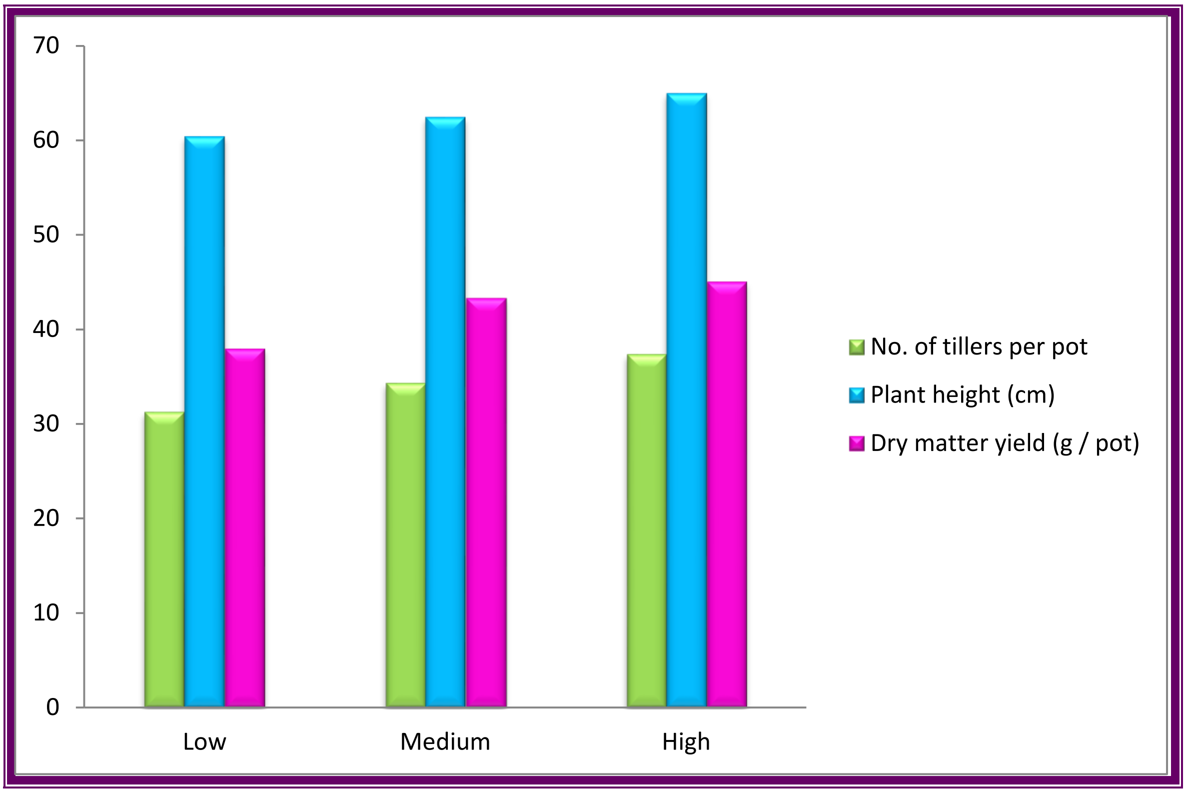

Fig. 1. Effect of soil potassium status on number of tillers, height and dry matter yield of paddy plant.

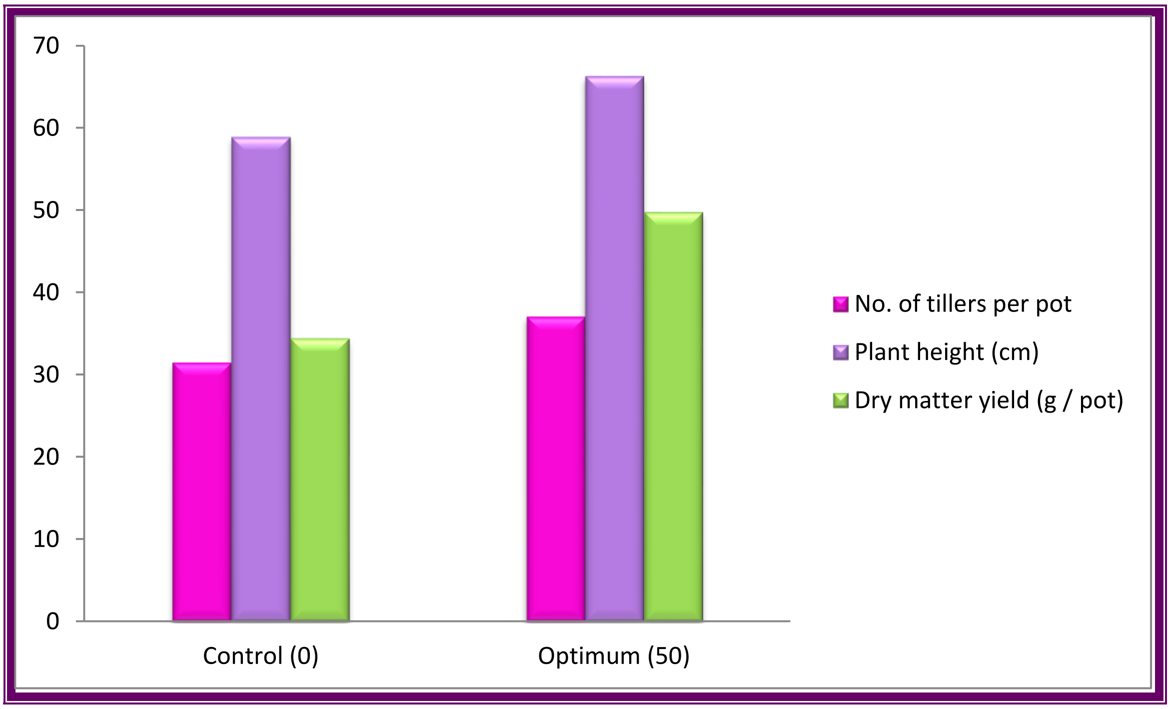

Fig. 2. Effect of potassium application (0 and 50 kg K_2O ha^{-1}) on number of tillers, height and dry matter yield of paddy plant.

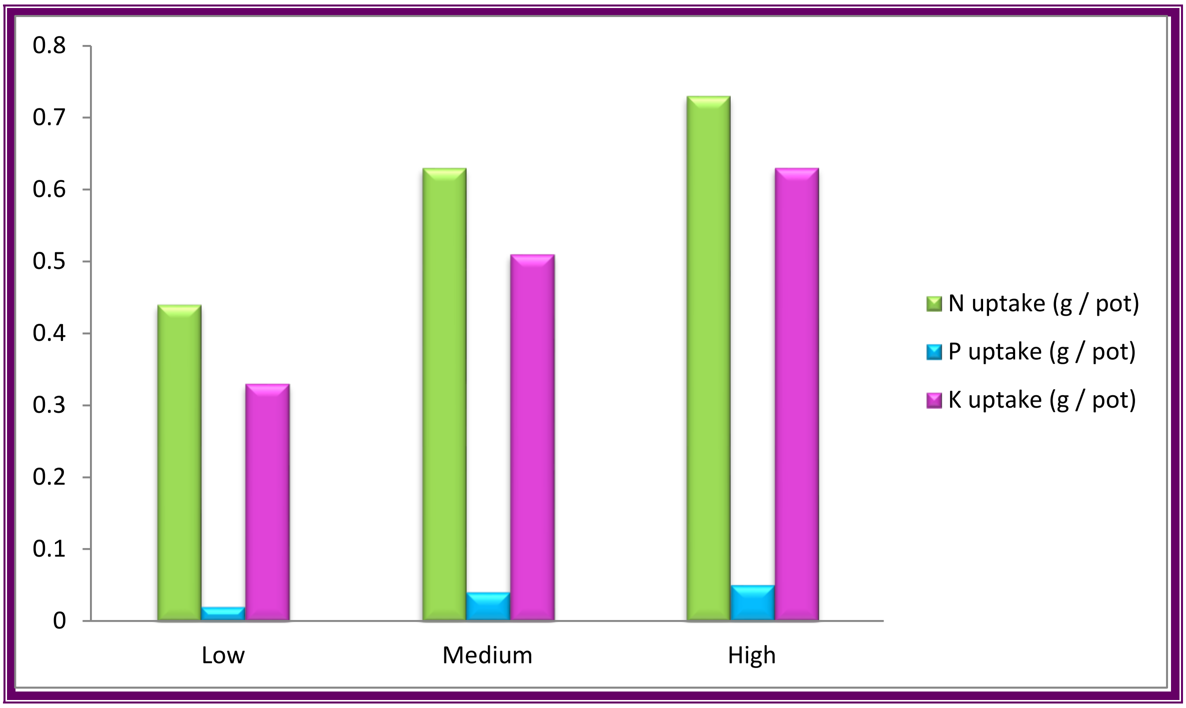

Fig. 3. Effect of soil potassium status on macronutrients uptake by paddy plant.

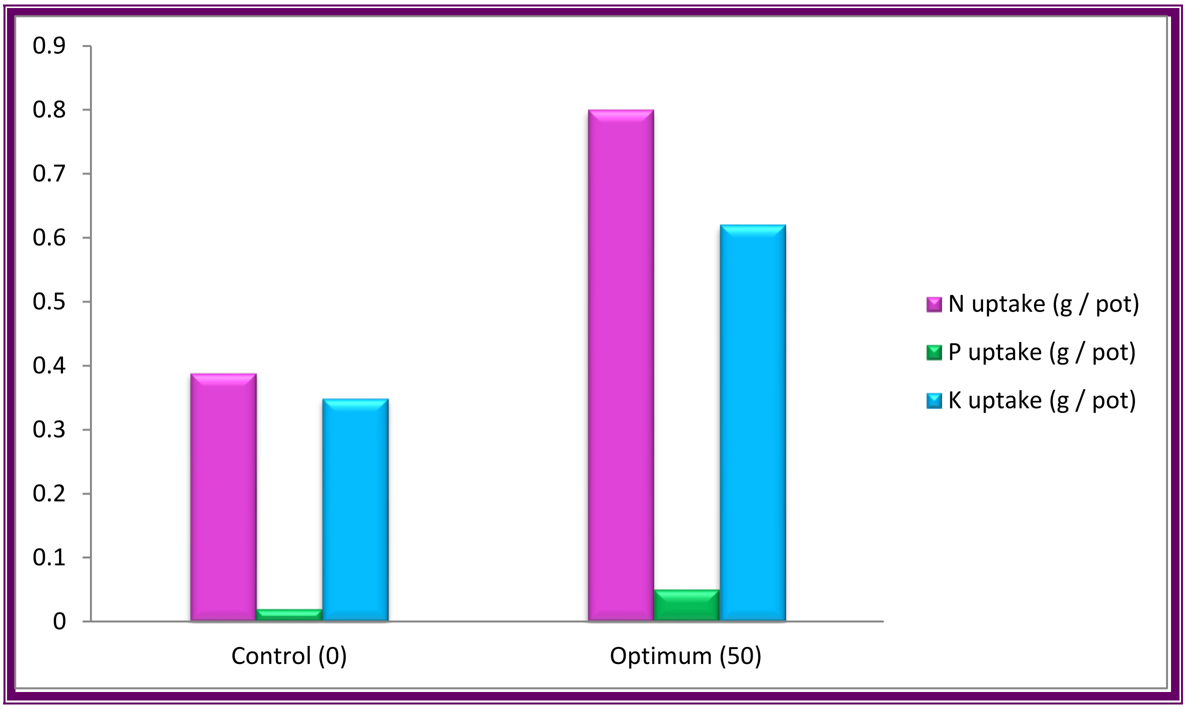

Fig. 4. Effect of potassium application (0 and 50 kg K_2O ha^{-1}) on macronutrients uptake by paddy plant.

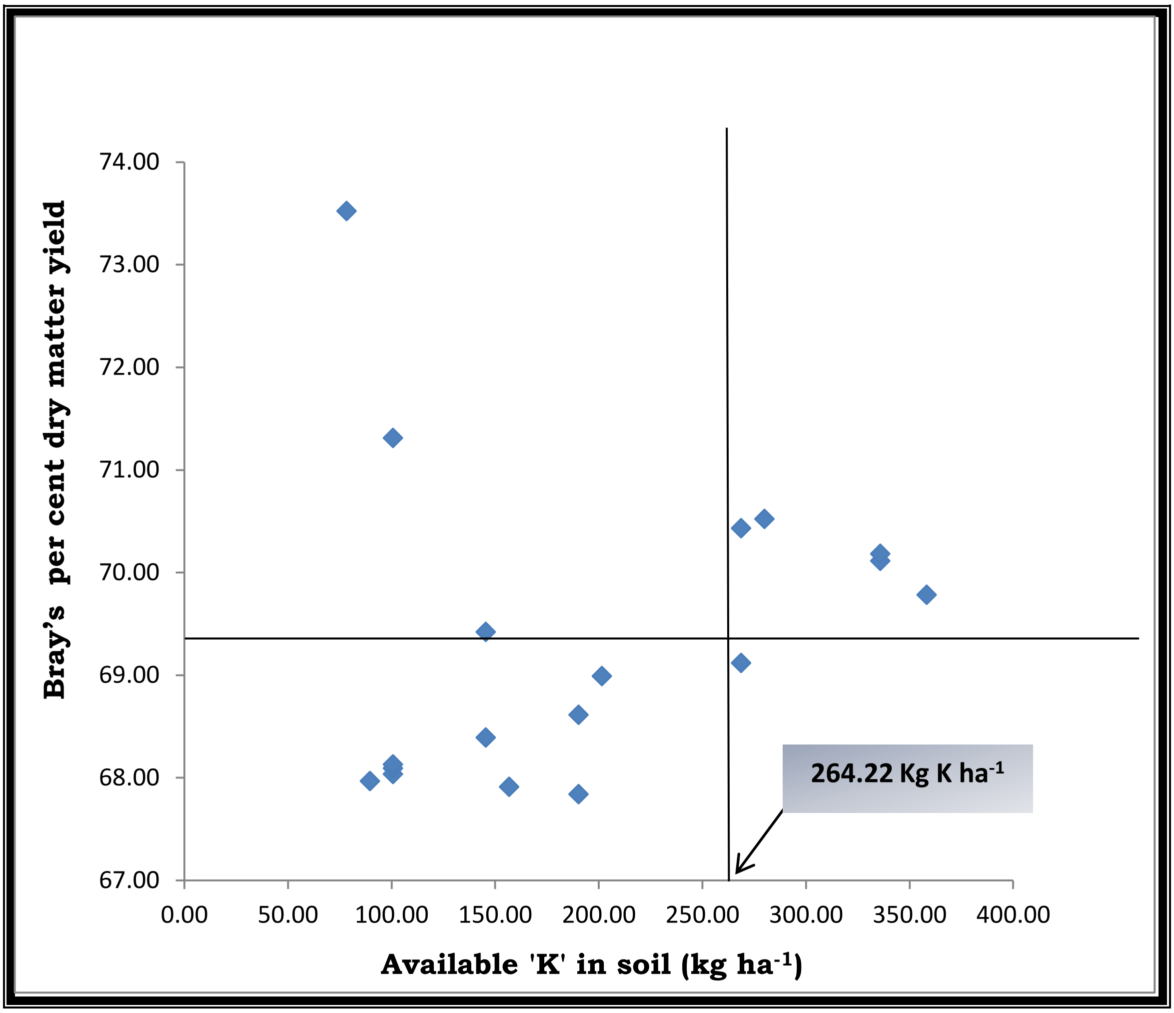

Fig 5. Scatter diagram for Bray's per cent yield of upland paddy v/s available 'K' in soil.

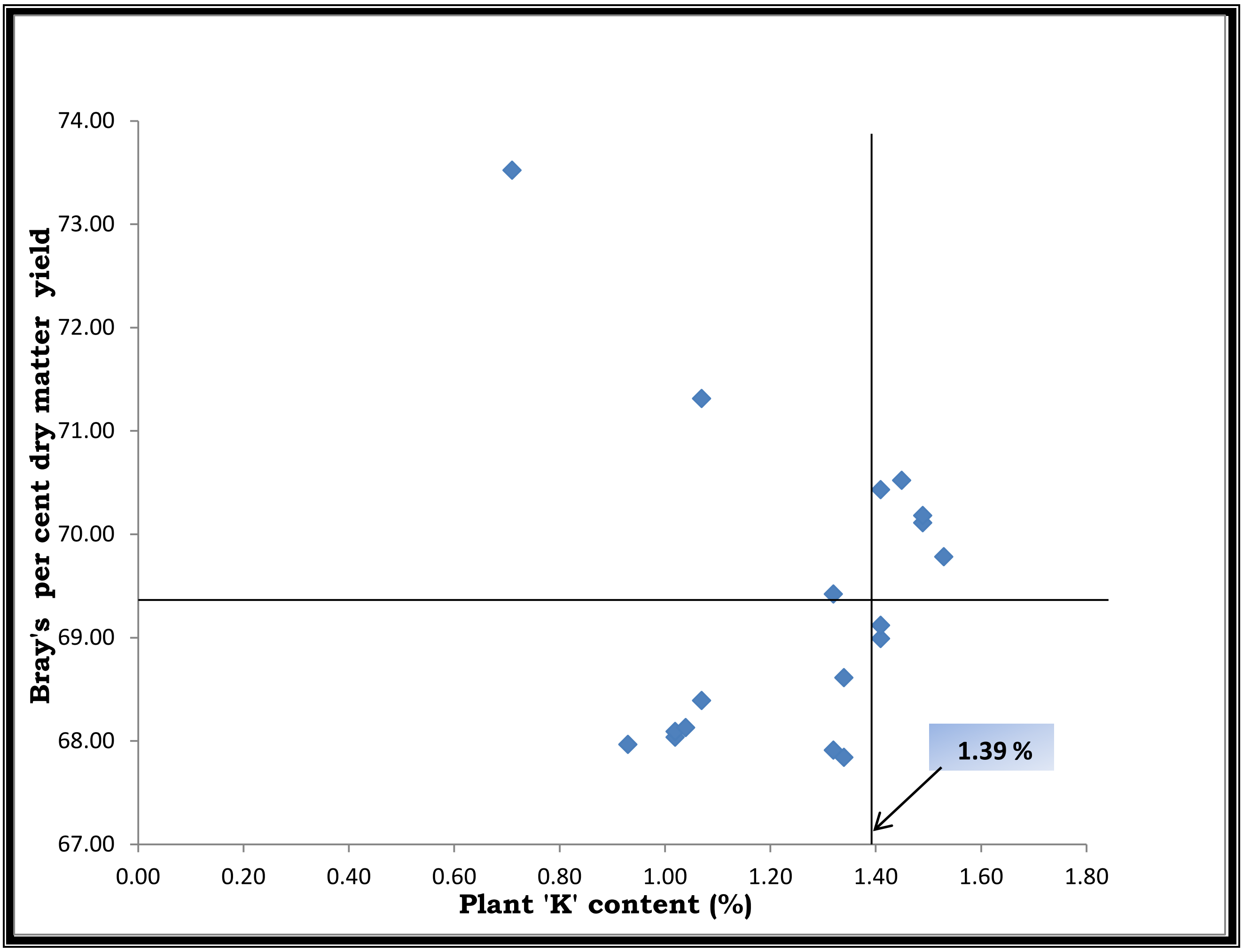

Fig 6. Scatter diagram for Bray's per cent yield of upland paddy v/s plant 'K' content.