Potassium release in soil amended with potassium bearing minerals

THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

Master of Science (Agriculture)
in
Soil Science and Agricultural Chemistry

Supervisor
Prof. Priyankar Raha

Submitted by
Priyanka Bharti

DEPARTMENT OF SOIL SCIENCE & AGRICULTURAL CHEMISTRY
INSTITUTE OF AGRICULTURAL SCIENCES
BANARAS HINDU UNIVERSITY
VARANASI – 221 005
INDIA

ID. No. 20412SAC008 **2022** **Enrolment No.391252**

BANARAS HINDU UNIVERSITY
(Established by Parliament by Notification No. 225 of 1916)
Department of Soil Science & Agricultural Chemistry
Institute of Agricultural Sciences
Varanasi- 221005

Dr. Priyankar Raha
Professor
Email rahapriyankar@gmail.com

Mobile: 9415381561
6306682007

Dated: / /2022

To,
The Registrar (Academic)
Banaras Hindu University,
Varanasi-221005 (India)

Sir,

I have great pleasure in forwarding the thesis entitled **"Potassium release in soil amended with potassium-bearing minerals"** submitted by **Ms. Priyanka Bharti**, (I.D. No. 20412SAC008**),** in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture)**in **Soil Science and Agricultural Chemistry**, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi.

I certify that the entire scheme of investigation presented herein was planned and carried out solely by the candidate under my guidance and supervision. The data presented in the thesis, to the best of my knowledge and belief, are genuine and original. No part of the work has been submitted for any other degree or distinction.

Thanking you,

Yours faithfully

Forwarded

(PRIYANKAR RAHA)
Chairman of the Advisory Committee

Head

POTASSIUM RELEASE IN SOIL AMENDED WITH POTASSIUM BEARING MINERALS

by
Priyanka Bharti

Thesis submitted in partial fulfilment of the
requirements for the degree of
Master of Science (Agriculture)
in
Soil Science and Agricultural Chemistry

Department of Soil Science and Agricultural Chemistry
Institute of Agricultural Sciences
Banaras Hindu University
Varanasi – 221005 (INDIA)

ID. No. 20412SAC008 **2022** **Enrolment No. 391252**

APPROVED BY ADVISORY COMMITTEE

Chairman

Dr. Priyankar Raha
Professor
Department of Soil Science and Agricultural Chemistry
Institute of Agriculture Sciences
B.H.U., Varanasi – 221005.

Members

Dr. A. Rakshit
Associate Professor
Department of Soil Science and Agricultural Chemistry
Institute of Agriculture Sciences
B.H.U., Varanasi – 221005.

Dr. R.S Meena
Assistant Professor
Department of Agronomy
Institute of Agriculture Sciences
B.H.U., Varanasi – 221005.

External Examiner

ACKNOWLEDGEMENT

Before I start inking let me truly admit that, it is practically impossible to mention all the worthy support, kind cooperation and directional guidance stretched out by my honourable teachers, loving parents, supportive friends and all of my well-wishers in just two pages. However, I am trying to document all worth-mentioning hereunder.

With a deep sense of devotion, I bow and pray to the feet of ***Lord Viswanath*** *who provided me with the choicest, everlasting blessing to get an opportunity to study at Banaras Hindu University, Varanasi, the dream of Mahamana Pandit Madan Mohan Malviya Ji, a great patriot, nobleman and patriarch of this university.*

With immense pleasure and a profound sense of gratitude, I take this opportunity to express my heartfelt and sincere thanks to my esteemed supervisor ***Prof. Priyankar Raha,*** *Professor, Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, for his meticulous guidance, indelible inspiration, persistent encouragement, ingenious suggestions, mellifluous nature and indefatigable attitude. I will ever cherish the elderly affection that he bestowed upon me throughout my tenure as a student under him which helped me to cope with many a trying situation.*

I owe my sincere thanks to ***Prof. B.P. Singh****, Head, Department of Geology, Institute of Science, Banaras Hindu University, for providing me with glauconite sandstone from the Son valley, Uttar Pradesh, during my course of investigation to work with glauconite.*

I sincerely express my gratitude and warmest regard to ***Prof. Nirmal De****, Head, the Department of Soil Science and Agricultural Chemistry for providing the necessary research facilities, critical suggestions and help during the course of investigation.*

I owe my sincere thanks to the members of my advisory committee, ***Dr. Amitava Rakshit****, Associate Professor, Department of Soil Science and Agricultural Chemistry, and* ***Dr. R.S Meena,*** *Assistant Professor, Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, for their critical suggestions, impeccable and directional guidance.*

I extend my indebtedness to ***Prof. Nirmal De (HoD), Prof. S. Singh, Prof. S. K. Singh, Prof. Janardan Yadav, Prof. A.K. Ghosh, Prof. P.K. Sharma, Dr. A. Rakshit, Dr. Y. V. Singh*** *and* ***Dr. R. Meena****, and I am thankful to all staff members* *of Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University for all kinds of help and cooperation to me during my study period.*

With profound regards in a more personal sense, I owe deepest debts to my revered parents ***Shri Lal Bahadur*** *and* ***Smt. Pramila Devi,*** *who taught me the value of wisdom based on erudition but without being enslaved by it and their persistent inspiration, selfless sacrifice, continuous encouragement and blessing gave untiring help and have enabled me to be what I am, today. I will also like to acknowledge my affection towards my Brother* ***Mr. Abhishek Kumar,*** *who was always with me during my ups and downs. I thank them once again for their kind cooperation.*

I would like to express my warm deep appreciation to my lab partner ***Mr. Aashish Ale*** *for his immense affection and help during my research work when I was ill during the course of my work and was always great support in all my struggles and confusion in my studies.*

I am grateful to my senior, ***Mukta Rani*** *for her advice, suggestions and help during the course of my work and for always motivating me for doing good in life.*

It is a pleasure for me to offer thanks to my friend ***Lokesh Kr. Parewa, Soumya Bhadani, Lilan Kr. Behera*** *and* ***Smita Bharti****.*

I wish to record my appreciation and sincere thanks to ***Mr. Shishir Kumar Singh, Mr. Anil Sharma, Mr. K.K. Singh, Mr. Agraj Pathak, Mr. H.N. Singh, Mr. Amrendra Kumar,*** *and* ***Abhishek bhaiya*** *non-teaching Staff members of the Department of Soil Science and Agricultural Chemistry for extending their kind cooperation and motivation during the entire course of this study.*

The graces of God are always blessed to me and give me patience and power to overcome difficulties which came my way in the accomplishment of this endeavour. I am very thankful to God for all His blessings and I pray to bless me always

Before I conclude, I confess that I do not know how to acknowledge the help and cooperation of my supervisor, members of the advisory committee, family members and relatives, seniors, juniors, and colleagues but the above feelings come from the core of my heart in the shape of words and as gospel truth.

Date:
Place: *Varanasi* **(Priyanka Bharti)**

CONTENTS

List of Symbols and Abbreviations

List of Tables

List of Figures

List of Plates

Chapter No.	Particulars	Page(s)
Chapter I	***INTRODUCTION***	**1-4**
Chapter II	***REVIEW OF LITERATURE***	**5-26**
2.1	Sources of potassium	
2.2	Processing of K-bearing minerals for fertilizer production	
2.3	Potassium-bearing minerals for fertilizer application	
2.4	Potassium release pattern from K-bearing minerals in the soil	
2.5	Kinetics of K-release from mineral fertilizers	
2.6	Future scope of K-bearing minerals as fertilizers for crop production	
Chapter III	***MATERIALS AND METHODS***	**27-49**
3.1	Description of the site of soil collection and the experiment	
3.2	Soil sampling and Processing	
3.3	Analysis of soil	
3.4	Soil Incubation	
3.5	Statistical Analysis	
Chapter IV	***RESULTS AND DISCUSSION***	**50-78**
4.1	Characterisation of soil under study	
4.2	Characterisation of potassium-bearing minerals under study	
4.3	Release of potassium from soil amended with potassium-bearing minerals	
4.4	Cumulative K release	
4.5	Release kinetics of potassium in soil	
4.6	Impact of soil amended with potassium-bearing minerals on electrochemical properties of soil	
4.7	Salt index values of potassic fertilizer materials	
Chapter V	***SUMMARY AND CONCLUSION***	**79-80**
	BIBLIOGRAPHY	**i-v**

LIST OF SYMBOLS AND ABBREVIATIONS

%	:	Per cent
˚C	:	Degree Celsius
$BaCl_2$	:	Barium Chloride
$CaCl_2$	:	Calcium Chloride
$CaCO_3$	:	Calcium Carbonate
CEC	:	Cation exchange capacity
cm	:	Centi meter
cmol(p$^+$) kg^{-1}	:	Centimole (proton) per kilogram
dSm^{-1}	:	Deci Siemens per meter
e.g.	:	For example,
EC	:	Electrical conductivity
EDTA	:	Ethylenediamine tetra-acetic acid
ESP	:	Exchangeable Sodium Percentage
et al.	:	And others
FAO	:	Food and Agriculture Organization
Fig.	:	Figure
g	:	Gram
g cm^{-3}	:	Gram per cubic centimeter
g kg^{-1}	:	Gram per kilogram
g mol^{-1}	:	Gram per mole
GPS	:	Global positioning system
h	:	Hour
ha	:	Hectare
i.e.	:	Which is to say, in other words
K	:	Potassium
KCl	:	Potassium Chloride
kg	:	Kilogram(s)
kg ha^{-1}	:	Kilogram per hectare
m	:	Meter
m	:	Metre
M	:	Molarity
meq l^{-1}	:	Milli equivalent per litre
mg kg^{-1}	:	Milli gram per kilogram

mg $kg^{-1}h^{-1}$	:	Milli gram per kg per hour
Mg m^3	:	Mega gram per meter cube
mL	:	Millilitre
mm	:	millimeter
MoP	:	Muriate of Potash
N	:	Nitrogen
NH_4OAc	:	Ammonium Acetate
No.	:	Number
OC	:	Organic carbon
pH	:	Puissance de hydrogen
ppm	:	Parts per million
rpm	:	Revolution per minute
SD	:	Standard deviation
SOC	:	Soil organic carbon
SOM	:	Soil organic matter
viz	:	That is to say

LIST OF TABLES

Table No.	Particulars
2.1	Different potash minerals with K_2O content
2.2	List of low-grade potash minerals and their major producer countries
2.3	World and regional potassium supply, demand, and balance 2016-2022(thousand tonnes K_2O)
3.1	Weekly meteorological data of Varanasi during the year of the experiment (April, 2021- March, 2022)
3.2	Treatment details at different stages of soil incubation
3.3	Weekly mean laboratory incubation temperature (^{0}C)
4.1	Physical and Chemical properties of experimental soil under laboratory incubation study
4.2	Characterisation of K-bearing minerals under study
4.3	Release of water-soluble potassium (H_2O-K) in soil treated with K-bearing minerals
4.4	Release of ammonium acetate extractable potassium (NH_4OAc-K) in soil treated with K-bearing minerals
4.5	Non-exchangeable potassium (HNO_3-K) in soil treated with K-bearing minerals
4.6	The cumulative amount of K released with time in soil treated with K-bearing minerals
4.7	Potassium release kinetics in soil treated with K-bearing minerals
4.8	Periodical changes of pH in soil treated with K-bearing minerals
4.9	Periodical changes of electrical conductivity (EC) in soil treated with K-bearing minerals
4.10	Salt index values of potassic fertilizer materials

LIST OF FIGURES

Figure No.	Particulars
2.1	Biotite and muscovite crystalline structures, as representatives of tri- or dioctahedral micaceous minerals
2.2	Potassium recovery methods from different natural sources
2.3	Solution mining process for potash extraction from K-bearing minerals
2.4	The process of froth flotation for extraction of potassium from minerals
2.5	Common potassium-bearing minerals used as fertilizers
2.6	Potassium release in 0.2 M NaTPB over time for different K-bearing mineral
2.7	The cumulative amount of K released with time in soils by successive extractions with 0.01 mol/L $CaCl_2$
2.8	First-order release kinetics of non-exchangeable K released by successive extraction with $CaCl_2$, Citric acid and HCl
2.9	Map of Potash bearing minerals exploration in Rajasthan, India
4.1	Release pattern of water-soluble K^+ (mg of K^+/kg of soil) in soil treated with K-bearing minerals
4.2	Release pattern of plant-available K^+ (mg of K^+/kg of soil) in soil treated with K-bearing minerals
4.3	Release pattern of non-exchangeable K^+ (mg of K^+/kg of soil) in soil treated with K-bearing minerals
4.4	The cumulative amount of K released (mg/kg) with days in soils treated with K-bearing minerals
4.5	Periodical changes of pH in soil treated with K-bearing minerals
4.6	Periodical changes of EC (dSm^{-1}) in soil treated with K-bearing minerals

LIST OF PLATES

Plate No.	Particulars
3.1	Location of soil under study
3.2	Soil sampling location in Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University
3.3	Laboratory incubation experiment
3.4	Mineral materials from commercial houses and from the natural system
3.5	Grinded materials of K-bearing minerals
3.6	Laboratory instruments used in the experiment

INTRODUCTION

Potassium is one of the most important nutrients for the growth and development not only of plants but also of animal and human life. There are different forms of potassium in soil *viz*., water-soluble, exchangeable, non-exchangeable (fixed), lattice K and mineral K. The percentage occurrence of potassium in the soil varies from place to place. Some soils derived from weathering of potassium-rich rocks will show high potassium content, but the proportion of non-exchangeable K and total K is always found to be more than water-soluble and exchangeable K in every soil **(Lalitha and Dhakshinamoorthy, 2014).** Potassium performs many physiological functions in plants hence different crops have different demand rates for potassium and when crop K demand is not fulfilled from soil reserves to produce high yields then all K needs are to be fulfilled by the application of potassium fertilizers in the soil. Many factors like soil mineralogy, demand of crop and efficiency of the crop to extract K determine the K uptake by plants. Fruit (banana) and vegetable crops extract the higher amount of K **(Anon.,2008-2009)** followed by cereal crops (finger millet, rice, wheat) and pulse crops (green gram, black gram).

An intensive cropping system is followed in countries like India, so every practice, Indian farmers neglect potassium application in contrast application of nitrogen and phosphorus provides a visible effect soon after their application. Hence Indian farmers preferred nitrogen and phosphorus as significant fertilizers for their crop production and neglected potassium, which affects the balance between plant nutrition and soil fertility. Indian agriculture showed a negative balance of K by depletion of K from 10.20 to 5.97 mt **(Tandon, 2004).** Balanced application of plant essential major nutrients i.e N, P, &K (nitrogen, phosphorus & potassium) proved to be very effective for crop production. Some of the experiments noticed high K uptake as compared to N in major crops like cereals and fodder crops **(Yadav *et al.*, 1998)**.

However, visible benefits of K fertilizer application on produce at the maturity stage in form of colour, shape, size and quality have encouraged farmers to use K fertilizers **(Kinekar, 2010).** Furthermore, the government of India has provided subsidies on the maximum retail price of K fertilizers in order to increase the use of these fertilizers.

The K in nature occur in the form of marine evaporite deposits and sedimentary rock deposits. The K fertilizers are obtained from processed ores of K-bearing minerals or sedimentary deposits of evaporites. These reserves of potassium-bearing minerals and rocks and their processing as fertilizer are limited to some the countries majorly like Canada, Russia, the USA, Israel and whereas in developing countries like India having no indigenous potassium mineral source has to completely depend on import from other countries for K fertilizers to meet the agricultural needs of their nation. The muriate of potash (MoP) is directly used as K fertilizer and also through complex fertilizers for crops and sulphate of potash is also used but at a low amount compared with MoP.

Agriculture in India is the major source of income and the country's economy. However, increasing population demand for food is the biggest challenge faced by the country and thus declining soil fertility affects crop productivity. Thus the present K demand is satisfied by highly soluble and concentrated mineral salts. These salt-based fertilizers when introduced to environments, affect the natural ecological diversity and ultimately deteriorate soil fertility. Hence the proper application of fertilizers is the major factor in retaining and enhancing soil fertility. The increase in the price of potash fertilizers is expected year to year on a global basis. As India imports K fertilizers to meet its domestic demand and invests millions of dollars in this. Thus, it becomes important for India to look for indigenous sources to meet the potash demand of the country. Potash mining prospects in India might help to alleviate the problem of mineral imports, which would have a good impact on investment opportunities in the industry, as well as to develop K fertilizers from K-bearing mineral riches in the long run.

Glauconite sandstone is a phyllosilicate mineral of the mica group and is rich in potassium about 4-8% K_2O **(Rakesh *et al.*, 2020).** Russia used glauconitic sandstone as a raw material for the preparation of K fertilizers **(Levchenko *et al.* 2008)**. Glauconite was used as slow-acting fertilizer in past by many countries, however with the introduction of highly soluble and concentrated K minerals in agriculture glauconite sandstone has lost its significance. India has the largest deposition of indigenous glauconitic sandstone in the Son Valley region, covering areas of Uttar Pradesh and Madhya Pradesh. In Rajasthan, glauconitic deposits occur in Kota, Karauli, Chittorgarh, Jaisalmer, and Barmer districts **(Rakesh *et al.*, 2020)**

Long-standing usage of glauconite as K fertilizer and its positive outcome can be used directly as fertilizer in acid soils, or it can be used in mixed form with compost manures or by treating with the organic acid or microorganisms producing organic acids or in glauconitic nanoparticle forms **(Praveen and Tomar, 2019)**. Glauconite is a natural source of potassium and is extremely beneficial for increasing soil fertility, crop production, food security, and environmental sustainability. As India does not have any exploitative marine deposit of potash (as green sand) but rather has glauconitic deposits, hence efforts can be made to make glauconite sandstone as a K- fertilizer as it has high CEC and supplies potassium along with phosphorus(P), and micronutrients like manganese (Mn), copper (Cu), and nickel (Ni) to a certain extent, but no contamination by toxic elements, low cost and lower contamination and deterioration to soil health. Hence it is it can be used as an alternative source of K fertilizers in India.

Keeping in view these facts, and the importance of glauconite sandstone as K fertilizer, this research work entitled **“Potassium release in soil amended with potassium bearing minerals”** was conducted by using chloride, nitrate and sulphate of potassium-bearing minerals *viz*. sylvinite, salt Peter and langbeinite, and glauconite sandstone from Son Bhadra district, Varanasi, Uttar Pradesh with the following objectives.

Objectives

1. Estimation of the release of water-soluble, readily available and slowly available potassium in soil amended with the K-bearing minerals.
2. Determination of release kinetics of potassium in soils amended with the K-bearing minerals.
3. Evaluation of the impacts on the soil reaction and soluble salts concentration in soil amended with the K-bearing minerals.

Chapter II

REVIEW OF LITERATURE

2.1 Sources of potassium

Potassium occurs profusely in nature, such as in

i. Sea water

ii. Rock- forming minerals

iii. Certain clay minerals in the land

iv. Rainwater

It has been estimated that around 5.10×10^4 tons of potassium is present in oceanic sources and around 8.30×10^9 tons of potassium abundance in terrestrial land (**Badri, 2010**). The total chloride content in **rainwater** is equal to the sum of sodium and potassium (**Larson and Hettick, 1956**) in rainwater, whereas Na content is three times higher than that of the K content.

Seawater is used (viz. dead sea in Israel and Jordan) as a commercial source of potassium recovery through chemical precipitation, solvent extraction, ionic exchange, and membrane separation techniques (**Jena, 2020**). The mined product of the buried ancient seas, viz. greensand in sea beds is also rich in potassium and directly used as fertilizer and soil conditioner.

The major **rock-forming minerals** (Table 2.1) for potassic fertilizer are generally soluble K-chlorides or sulphates, *viz.* sylvite (KCl), kainite [$KMg(SO_4)Cl.3H_2O$], carnallite ($KCl.MgCl_2.6H_2O$), langbeinite ($K_2SO_4.2MgSO_4$) and polyhalite [$K_2Ca_2Mg(SO4)_2.2H_2O$], which are widely used for industrial fertilizers of potassium. These chlorides and sulphate rock-forming minerals are evaporites that are formed by evaporation of seawater or saline inland lakes followed by crystallization.

Some **clay minerals** are also rich sources of potassium (15-17% K). Illite is a clay mineral that contains approximately 7% of K_2O. Illite is generally rich in heavy soil (i.e. black soil).

Although the rich sources of K are chlorides and sulphates evaporite minerals, but these minerals are not available in many parts of the world. Thus**, low-grade K-bearing minerals** *viz*. feldspar, mica, biotite, muscovite, and glauconitic sandstone (Table 2.2) should be the alternative potential sources of K-bearing minerals. Glauconitic sandstone is one of the major alternative minerals sources for potassic fertilizers. A large deposit of glauconitic sandstone is found, in Rajasthan **(Monhot *et al*., 2005),** Madhya Pradesh, and Uttar Pradesh (**Singh *et al*., 2014**) of India containing 5-6% K_2O. The total potassic mineral in India is estimated to be 21816 million tonnes by 2010 **(Prakash and Verma, 2016)**, out of which Rajasthan contributes 94% followed by Madhya Pradesh with 5%, and Uttar Pradesh with the remaining 1%.

In the soil environment, feldspar and mica weathering are related to the availability of potassium to plants **(Pal and Srinivasrao, 2001)**. K-feldspars account for around 16 % K of the total, whereas K-micas account for about 5.2 % **(Ahrens, 1965)**. In micas, biotite constitutes a major portion of 3.8% and muscovite only 1.4% of K. The muscovite is dioctahedral and biotite is trioctahedral, micas have ditrigonal cavities of the basal plane of oxygen of tetrahedral sheets where large unhydrated K ions are held by electrostatic bonds this keeps layer. Hence K is released more easily in trioctahedral micas as compared to dioctahedral micas **(Mortland *et al*.,1957)**.

2.2 Processing of K- bearing minerals for fertilizer production

Minerals contain many other impurities which are removed through various processes and the required constituent of potassium is purified and concentrated into fertilizer form. Processing methods (Fig. 2.2) depend on the type of mineral source: sea sources and mineral sources. Potassium from water-soluble sources can be extracted using solution mining or conventional mining, potassium recovery from rocks and minerals can be done by processes like physical separation, bio-leaching, chemical leaching, flotation, and roast leaching and processes like chemical precipitation, solvent extraction, ionic exchange, membrane separation can be used for potassium recovery from sea sources **(Jena, 2020)**.

In solution mining or conventional mining process hot solvent (water) is injected through a drill hole into an underground soluble potash reserve thereafter dissolved salts are pumped out and transferred to another drill hole for further processing for removing impurities like other salts, clay particles, and non-clay minerals.

Bioleaching is a method of processing potassium occurring in rocks and minerals by the use of microorganisms like *Bacillus mucilaginosus, Aspergillus niger, Penicillium oxalicum, Aspergillus oryzae,* etc. Organic acids (acetic acid, citric acid, butyric acid, lactic acid, formic acid, etc.) and alkalis (ammonia or amines) produced by microorganism weaken and breaks the Si–O–Si and Al–O framework bond thus potassium is released and can be easily used by plants (**Bosecker, 1997; Sheng *et al*., 2008; Alori *et al*., 2017 and Mustoe, 2018**) as fertilizers.

In the froth flotation technique of mineral processing, hydrophobic materials are selectively separated from hydrophilic materials. The mineral ore is crushed to particles of the desired size are mixed in the collector which functions as a surfactant that enhances the hydrophobic nature of the mineral. The slurry of minerals gets converted to pulp and added to a container where an air jet is forced resulting in the formation of bubbles. The required mineral (hydrophobic) gets repelled by water and thus gets attached to the air bubbles when these bubbles rise to the surface along with the attached mineral in the froth. This froth is separated mechanically and processed further.

The chemical leaching method of mineral processing involves crushing mineral ore into a smaller size than supplied for leaching where water, acid, or alkali solutions are added simultaneously at fixed temperature and pressure for a fixed reaction time. After that solution produced is processed for potassium recovery.

In the roast leaching method, potassium mineral is roasted in presence of an additive (chloride salt) for a specific time. **Hao *et al*. (2012)** reported that feldspar of particle size of 75 microns on roast leaching at 800°C for 1h extracts 95.35% of potassium from feldspar in presence of additives like $CaCl_2$ and NaCl in the ratio of 1.8:1.1:0.6 of feldspar to $CaCl_2$ to NaCl.

2.3 Potassium-bearing minerals for fertilizer application

Potassium has a crucial role in the physiological functions of plants and crops demand for potassium is almost as significant as nitrogen and phosphorus K fertilizers application is low in India and continuous crop cultivation with no K application leads to soil K mining by crops and thus inadequate and insufficient K application leads to K deficiency symptoms in crops which reduces yield and quality. Hence K application should be done according to specific crop requirements and coinciding with the stages of crop requirement of K; crops replenish less than 50% of the potassium absorbed by them **(Smil., 1999).**

Li *et al*., (2015) investigated that with the deficiency of potassium in the soil, dependence on exported fertilizers, and decreasing agricultural production cost potential K-bearing phyllosilicate minerals can be directly used as an alternative source of fertilizers.

A mineral source of potassium is the K- bearing minerals with high potassium concentration. (**Basak *et al*., 2017**). The primary minerals like mica, feldspar, illite, vermiculite, and chlorite are sources of K in soil. Sylvite, carnallite, langbeinite, niter, polyhalite, and kainite are the minerals most typically utilized in the commercial synthesis of K fertilizers. The majority of the production is made up of sylvite and carnallite. The majority of K fertilizers that are used in crop cultivation are sourced from evaporation deposits of sea salts like potassium sulphate or sulphate of potash or arcanite (K_2SO_4), langbeinite (sulphate of potash-magnesia), magnesia-kainite and sylvinite.

Table 2.1 Different potash minerals with K_2O content

Minerals	Chemical formula	K_2O (approx.; %)
Orthoclase	$KAlSi_3O_8$	16
Mica (Muscovite)	$KAl_2(AlSi_3O_{10})\ (OH)_2$	8-12
Nepheline syenite	$Na_3KAl_4Si_4O_{16}$	5-7
Kainite	$MgSO_4 \cdot KCl.3H_2O$	19
Langbeinite	$MgSO_4 \cdot K_2SO_4$	22
Carnallite	$KCl \cdot MgCl_2 \cdot 6H_2O$	17
Microcline	$KAlSi_3O_8$	15-17
Polyhalite	$K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$	16
Alunite	$K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 4Al(OH)_3$	11
Feldspar	$KAlSi_3O_8$	5-14
Glauconite	$(K,Na)(Fe^{3+},Al,Mg)_2(Si, Al)_4O_{10}(OH)_2$	4-8
Sylvinite	KCl	63

Source: Jena, 2020, Mining, Metallurgy and Exploration

Table 2.2 List of low-grade potash minerals and their major producers

Minerals	Major producers	World production data (metric tons)
Feldspar	Italy, Turkey, China, Thailand	20,875,000
Nepheline syenite	Norway, Russia, Canada, Iran	5,548,000
Mica	Finland, France, Russia, Spain	307,000
Glauconite	North Europe, India, Egypt	NA (not available)

Source: Brown *et al*. (2013), British Geological Survey.

2.3.1 Potassic fertilizer application methodology

There are different techniques of potassium fertilizer application that are applied depending on the types of crops, types of soil, and the types of fertilizer (solid or liquid). In annual crops, methods like side-band placement, band application, and broadcasting are efficient methods, whereas for perennial forage crops broadcasting and pre-sowing incorporation with high doses of potassium fertilizers are suitable in areas of K-deficient irrigated land.

Welch *et al*. (1966) investigated the relative efficiency of the broadcast and band method of K fertilizer application in the corn crop. He experimented on 3 types of soils: Cisne, Belknap, and Bluford of Illinois. He found that to obtain a specified yield, less amount of K was required through band application than in the broadcast method. The highest yields of crop was observed by broadcast K for the Cisne and Bluford soils, but a higher rate of broadcast K was required. However, in the case of Belknap soil, even the highest rate of broadcast K did not attain the yield produced at the highest rate of banded K. On Cisne soil, for the same yield of corn, the rate of broadcast K was 30.4 and 106.6 pounds per acre and the rate of banded K was at 10 and 50 pounds per acre. In all the three soils, broadcast K proved to be less efficient than banded K.

Hewedy (2000) evaluated the efficiency of some K application methods, such as soil dressing at two rates, 48 and 96 kg K_2O/fed., or foliar spray with a 2% potassium sulphate solution and 3% liquid potassium fertilizer (37 percent K_2O), and noticed that soil dressing at 96 kg K_2O/fed gave the best yield and fruit quality. While the result showed no significant differences in earliness, fruit set, and fruit yield between two soil dressing rates of 48 kg K O/fed and foliar spraying with a 2 percent potassium sulphate solution or a 3 percent liquid potassium fertilizer.

Ali *et al*. (2005) investigated the effectiveness of various K fertilization strategies (band placement, broadcast, and fertigation) in rice (cv. 385) before 25 and 50 days after transplanting (DAT). Band placement of K fertilizer at 25 DAT in furrows, broadcast, and fertigation showed enhancement of potassium content in paddy. On the other hand, K application at 50 DAT by broadcast and fertigation or incorporation before transplanting showed comparatively less K content. The highest uptake was observed when K was applied at 25 DAT, either by broadcast or fertigation, and band placement of K in furrows. The uptake of potassium by paddy occurred in the following order: fertigation at 25 DAT >band placement in furrows > broadcast at 50 DAT > fertigation at 50 DAT >fertigation at transplanting > broadcast and incorporation > control.

2.3.2 Impact of K-bearing mineral fertilizers on crops

K-bearing minerals are naturally occurring and are rich in potassium hence, these can be used alternatively in place of processed fertilizers to address the potassium deficiency in soil and decrease agricultural production costs. Primarily micaceous minerals and evaporites like polyhalite are rich in k-bearing minerals.

Coroneos *et al*. (1996) investigated the efficiency of granite as K-source in a glass house pot experiment in South Western Australia within three acid soils with the following treatment: a control with no K application, a KC1 treatment at the rate of 90 mg K kg^{-1} soil, and a granite treatment at the rate of 20 g granite kg^{-1} soil. Subterranean clover (*Trifolium subterraneum*) and ryegrass (*Lolium rigidum*) were cropped in pots for 7 weeks and after harvesting allowed to regrow for another 13 weeks. For 7 weeks Clover showed growth in the following order: control < granite < KCl but ryegrass did not show any significant difference between growth for granite and control. After another 13 weeks, both crops showed remarkable growth in granite application.

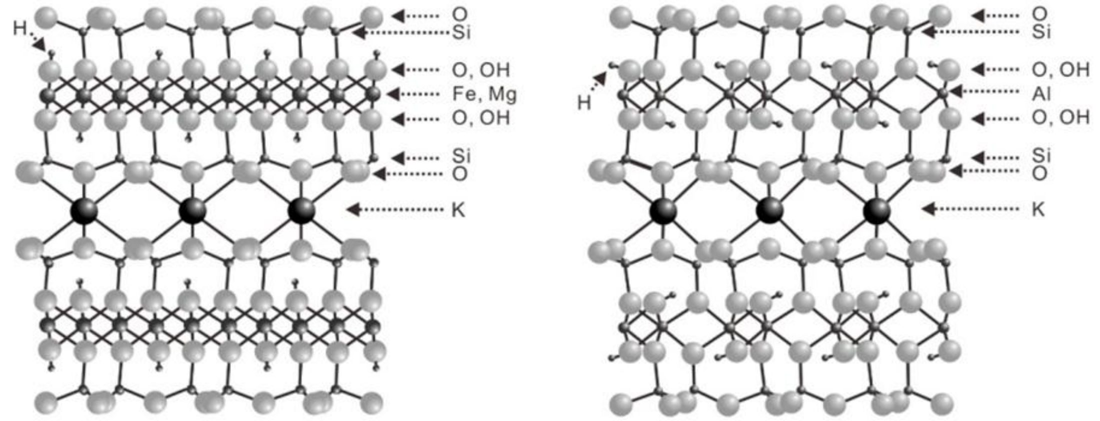
Labib *et al*. (2012) conducted a field experiment to evaluate the effect of potassium-bearing rock on the growth and quality of potato crops (*Solanum tuberosum*) in poor sandy soils. According to the requirements of potassium for crops, four treatments were used: 1st treatment is control using **K-sulfate** only; 2nd treatment is **½ K-sulfate +½ K-feldspar**; 3rd treatment is **¼ K-sulfate +¾ K-feldspars** and 4th treatment **K-feldspars only**. The total yield of vegetative plants and tubers for all four treatments follows the order: 2nd treatment > 1st > 3rd > 4th.

Treatment 2nd showed significantly higher K- content in the plant while no significant differences were found for micronutrients (Fe, Mn, Zn, and Cu) among the four treatments. It was observed that the fourth treatment obtained high-quality potato tubers in spite of the lower yield.

Karimi *et al*. (2012) evaluated the potential of glauconitic sandstone as K source applied @ 400g glauconitic sandstone powders per 10L in hydroponics and in sand culture for olive plants. Plants fed with 400g glauconitic sandstone observed higher growth in the hydroponic culture than the sand culture. Thus, K^+ was released from the glauconitic sandstone and it can be amended in soil in combination with other potassium fertilizers.

Li *et al*. (2014) explored the potential of phyllosilicate minerals (*viz*. biotite, muscovite, phlogopite, illite, vermiculite and smectite containing K_2O as 6.73, 9.18, 10.02, 9.68, 2.26 and 3.92%, respectively) for intensive cropping with perennial ryegrass. It was noticed that biotite and vermiculite were the potential alternatives to the use of classical K fertilizers, illite can be utilized in combination with KCl/K_2SO_4, whereas muscovite, phlogopite and smectite were not found suitable for plant growth.

Mohammed *et al*. (2014) used leek (*Allium ampeloprasum* var. porrum L.) as a model plant to compare three silicate minerals, microcline (feldspar), biotite (mica), and nepheline syenite (nepheline+ microcline) for the availability of K to plants grown in sandy soil. KCl was used to compare the performance of these silicate minerals. This experiment demonstrated that yields obtained with biotite were observed closely advance towards the maximum yields spotted for KCl. Nepheline syenite gave an intermediate outcome and the least was observed for microcline.



Biotite **Muscovite**

Fig. 2.1 **Biotite and muscovite crystalline structures, which are representatives of tri- or di-octahedral micaceous minerals**

(Source: **Kitayama *et al*., 2019**)

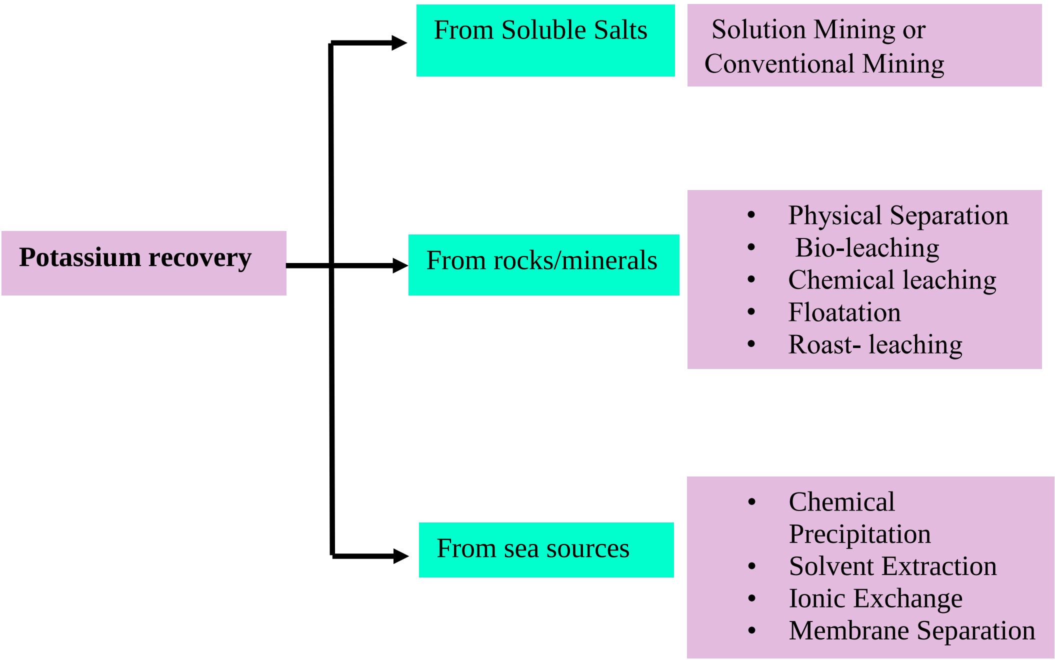


Fig. 2.2 Potassium recovery methods from different natural sources

(Source: **Jena, 2020,** Mining, Metallurgy & Exploration)

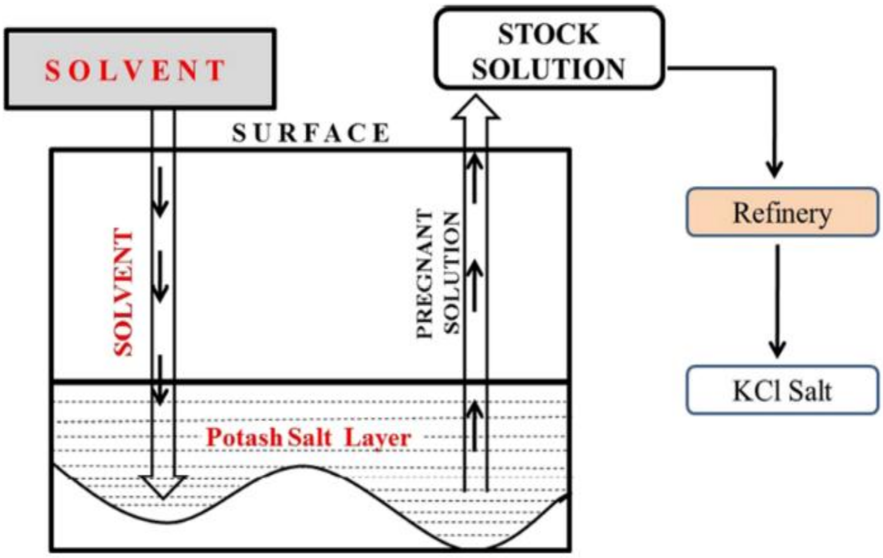


Fig. 2.3 Solution mining process for potash extraction from K-bearing minerals

(Source: **Helvenston *et al*.**, 1965 Patent Serial No. 456120,1965)

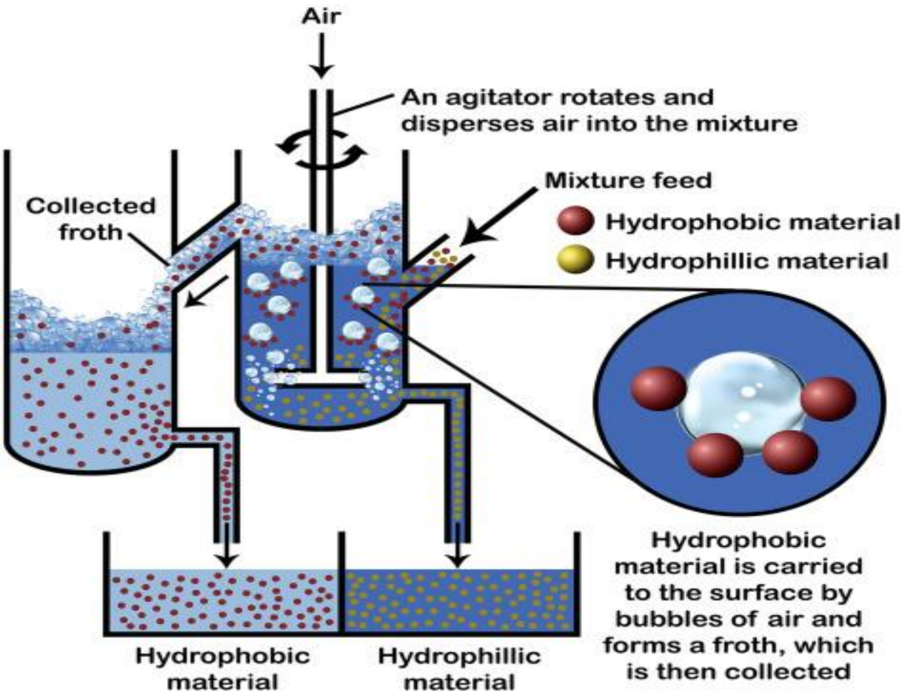


Fig. 2.4 The process of froth flotation for extraction of potassium from minerals

(Source: **Crawford and Quinn, 2017**)

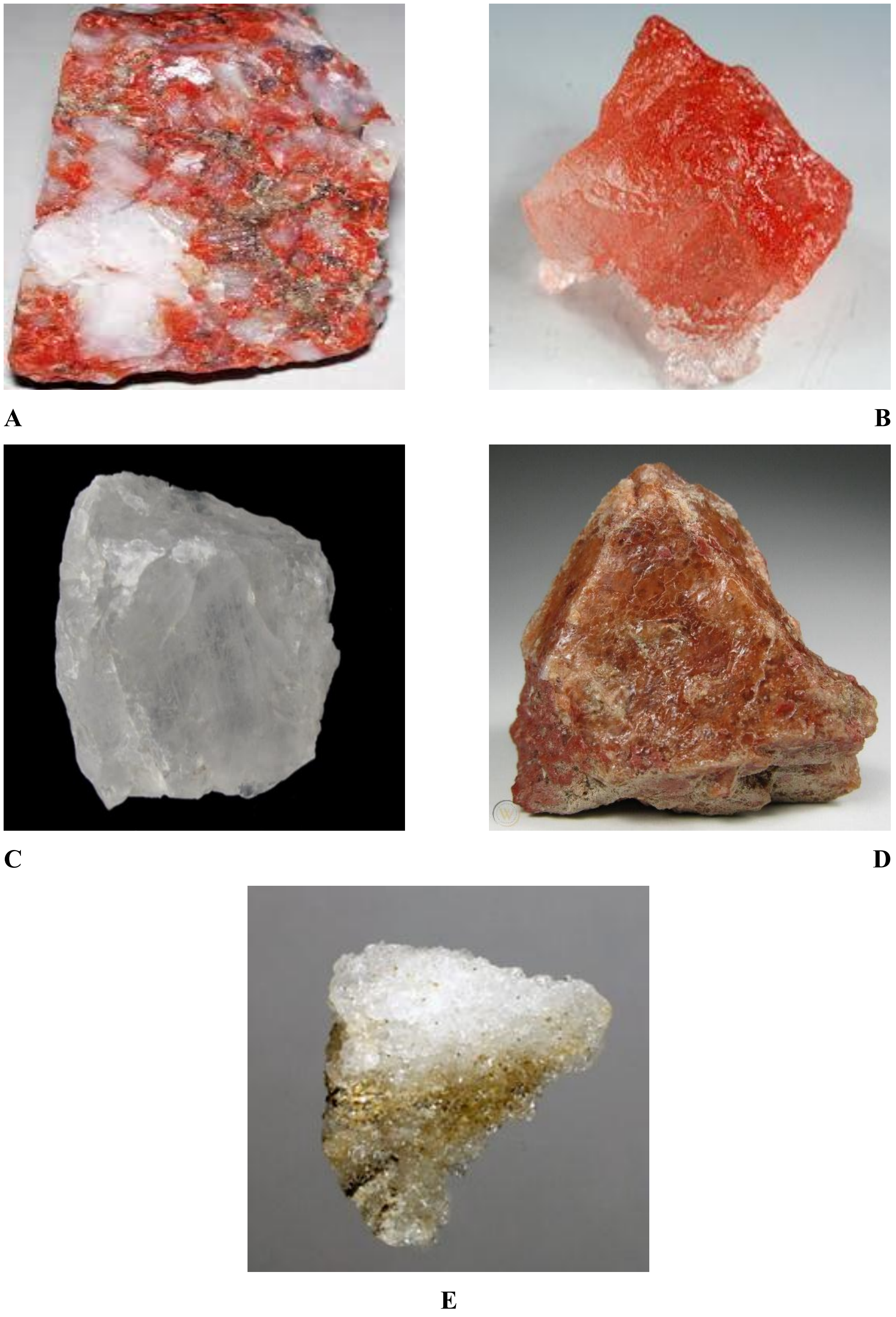


Fig. 2.5 **Common potassium-bearing minerals used as fertilizer (A) Sylvinite; (B) Carnallite; (C) Kainite; (D) Langbenite; (E) Niter**

2.4 Potassium release pattern from K-bearing minerals in the soil

The rate of potassium (K) release from soils is a dynamic process that is important in determining the amount of K available to plants in the soil.

K-feldspars and phyllosilicate minerals are the most abundant sources of K-bearing minerals and rocks that can be used as alternative K fertilizers. The selection of the best mineral to be used as fertilizer primarily depends on the rate at which potassium is released into more adjustable or labile forms, so that plants can easily utilize it. The release of potassium from mica first advances the transformation by exchanging the K of mica with hydrated cations to extensible 2:1layer silicates, followed by dissolution of mica and formation of weathering products. In the case of potassium feldspar, there is a rapid exchange of H^+ to the release of K from feldspar followed by continued dissolution, biological activity,

There are various factors that govern the release of potassium from mica by cation exchange reactions and dissolution. These include the chemical composition, particle size degree of tetrahedral tilting and rotation, wetting and drying, degree of K depletion, cell dimension, inorganic cations, the activity of K^+ and other factors **(Sparks and Huang, 1985).** Researchers **(Sprengel, 1826; Bolton, 1882; Huang and Keller, 1970)** have recognized the involvement of organic acids in weathering of rock-forming minerals. **Song and Huang (1988)** observed the impact of oxalic acids and citric acid on the dynamics of potassium release from mica and feldspar. In presence of oxalic and citric acids, potassium release sequence from mica and feldspar follows order as biotite> microcline > orthoclase > muscovite.

Cox and Joern (1996) found that after 96 hours of incubation with NaTPB, K release from the interlayer of phyllosilicate clay minerals was nearly complete in all soils. They evaluated the period of potassium release ranging from 5 minutes to 96 hours. The cumulative release of K increased with time ranging from 0.20–5.73 g/kg at 5 min. to 1.31–48.30 g /kg at 96 h. Biotite showed a maximum potassium release of 48.30 g/kg whereas muscovite and smectite showed minimum potassium release of 1.69 and 1.31 g/kg, respectively at 96 h. At 96 hours, the cumulative release of potassium from illite and vermiculite was four times greater than the cumulative release of potassium from phlogopite. To observe the K release pattern, the K release values were plotted against time (Figure2.6). Except for phlogopite, which showed a continuous trend of fast release during the extraction time, K release was faster during the first 2 hours and then significantly slower after that.

The influence of oxalic acid on the release kinetics of K from soils [black soil (mollisol), red soil (ultisol) and calcareous alluvial soil (entisol) of China] from K-bearing minerals *viz.* biotite, pholopite, muscovite and microcline was investigated by **Shu-xin, *et al*. (2007)**. An oxalic acid solution with low pH was able to release more amount of K from K-bearing weathered minerals in soil with higher pH values, particularly in red soil. The order of K-release from K- minerals was ranked as biotite> phlogopite >> muscovite > microcline and in respect of soil, it was in the order: black soil > calcareous alluvial > red soil. The decrease in K^+ adsorption and increase in K^+ desorption in presence of oxalic acid is the basic mechanism of greater K^+ release from minerals to soils.

Glauconite is a naturally occurring and abundant K-bearing mineral and has the potential to alternative source of K-bearing fertilizers for crops. But the solubility and release of K from glauconite is a serious problem. Further plant root exudates containing organic acids *viz*. oxalic acid, acetic acid, malic acid, citric acid and acetic acid enhance the solubility of glauconite amended in soil. **Praveen** and **Tomar (2019)** evaluated the solubility of nano-glauconite mineral particles in presence of organic acids, generally release in high amounts from maize, *viz*. oxalic acid, malic acid, citric acid and acetic acid. Among the four representative maize root exudating organic acids, oxalic acid noticed a maximum (15.53mg K^+/L) solubilizing effect on nano-glauconite mineral particles, whereas the least solubilizing effect was water (1.67 mg K^+/L of water).

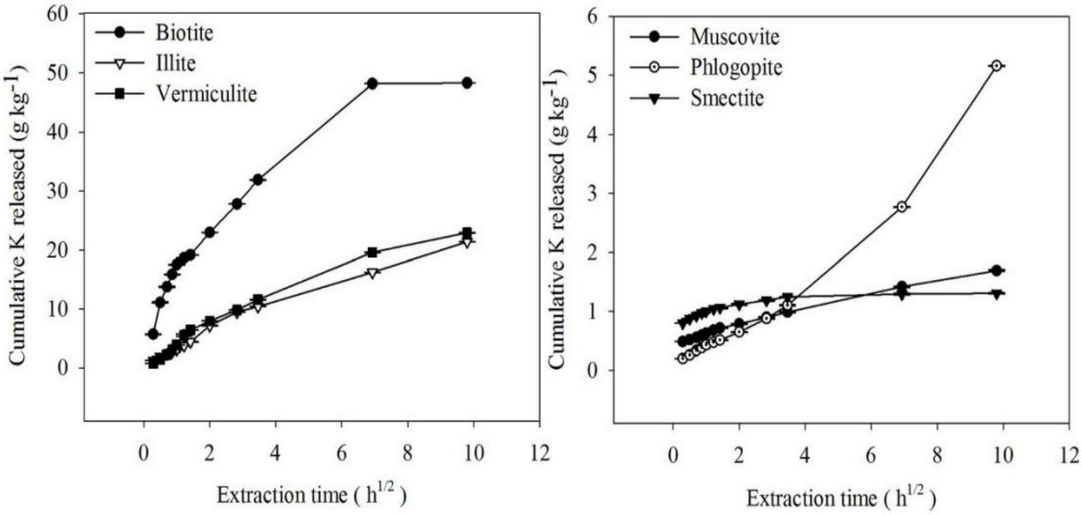


Fig. 2.6 **Potassium release in 0.2 M NaTPB over time for different K-bearing mineral**

(Source: **Cox and Joern, 1996**)

2.5 Kinetics of K- release from mineral fertilizers

A significant proportion (90-95%) of the potassium needs of crops are met from the non-exchangeable fraction of soil K **(Srinivasrao *et al*., 2000)**. The source of non-exchangeable K in soils is rich in 2:1 clay minerals *viz*. micas and vermiculite. Moreover, the release of K from the interlayer of these minerals may be very low, which are depending on the weathering stage of these minerals. Therefore, for optimal crop growth, soil solution and exchangeable K need for optimal crop growth; soil solution and exchangeable K need to be replenished with K through the release of non-exchangeable K or the addition of mineral sources of K and organic matter containing K.

Hosseinpur *et al*. (2012) studied the potassium release characteristics in surface soils of 15 calcareous soils and the relationship between these parameters and bean plant indices. The findings of this study revealed that data from laboratory K release studies and kinetics equation parameters can be used to estimate soil K supplying power. The kinetics of K release were studied using 0.01 mol/L $CaCl_2$ extractions over a period of 2–17 hours at 25± 1°C. The cumulative K release ranged from 111 to 411 mg/kg, according to the findings. A plot of the cumulative amount of K released revealed a slope discontinuity at 168 hours. Thus, for segments of the total reaction time (2 to 168 and 168 to 2017 h), two equations were used. The amounts of K released during 2–168h and 168–2017 h were 55–299 mg/kg and 44–119 mg/kg, respectively. In two segments, the release kinetics of K matched parabolic diffusion, simplified Elovich, and power function models fairly well. Potassium released after 2–168 and 168–2017 h, as well as K release rate constants, were significantly correlated (P 0.05) with bean plant indices, whereas there was no significant correlation between K extracted with 1 mol/L NH4OAc (ammonium acetate) and plant indices.

Srinivasarao *et al*. (2007) investigated the release kinetics of non-exchangeable potassium(K) of six key Indian benchmark soil series as influenced by clay and silt fraction mineralogy and soil depth. Smectitic soils had the highest first-order release rate constants, followed by illitic and kaolinitic soils. The 0.01 M citric acid medium had the highest release rate constants in all soils, followed by 0.01 M $CaCl_2$ and 0.01 M HCl. Smectitic soils had rate constants ranging from 99.99 to 101.55 X 10^{-4} h, illitic soils from 81.02 to 91.38 X 10^{-4} h, and kaolinitic soils from 63.81 to 81.26 X 10^{-4} h. In citric acid media, the mean rate constants were 91.40 10^{-4} /h, 84.45 10^{-4} /h in $CaCl_2$, and 81.47 10^{-4} /h in HCl media. Smectitic soils (353 mg K kg^{-1} at 0- to 15-cm depth and 296 mg K kg21 at 15- to 30-cm depth, averaged for 2 soils and 3 extractants) released more non-exchangeable K than illitic (151 mg K kg^{-1} at 0- to 15-cm depth and 112 mg K kg^{-1} at 15- to 30-cm depth) and kaolinitic (194 mg K kg^{-1} at 0- to 15-cm depth). In smectitic and illitic soils, surface soils had higher cumulative K release, but kaolinitic soils had higher cumulative K release in the subsurface soils.

Jalali1 and Khanlari (2014) investigated the effects of various land uses on K release from calcareous soils in western Iran's agricultural areas. The kinetics of K release (0.01M $CaCl_2$ were investigated in surface samples of 62 calcareous soils of pasture, orchard, garlic, green vegetables, wheat, and potato cultivated lands the kinetics of K release in 0.01M $CaCl_2$ were investigated. The kinetics of the K release were similar across land use categories. The lowest K release was found in pasture land samples (245.2 mg kg^{-1}), whereas the highest values were seen in leafy vegetable samples (449.6 mg kg^{-1}). The soil K release rate was calculated using a parabolic equation, and it differed significantly between land use categories. The release rate of pasture and wheat (averaged 16.1 and 25.1 mg kg^{-1} $min^{-1/2}$, respectively) was lower than that of leafy vegetables (27.4 mg $kg^{-1}min^{-1/2}$) and potato (27.0 mg $kg^{-1}min^{-1/2}$). When the rate of K released from the parabolic model was regressed on K forms and soil variables, the most relevant K forms and soil properties impacting K release rates in these calcareous soils were NH_4OAc-K, $CaCl_2$-K, pH, and EC. Diverse K release and NH_4OAc-K or $CaCl_2$-K prior to K treatment should also be considered when applying potassium fertilizer to different land uses.

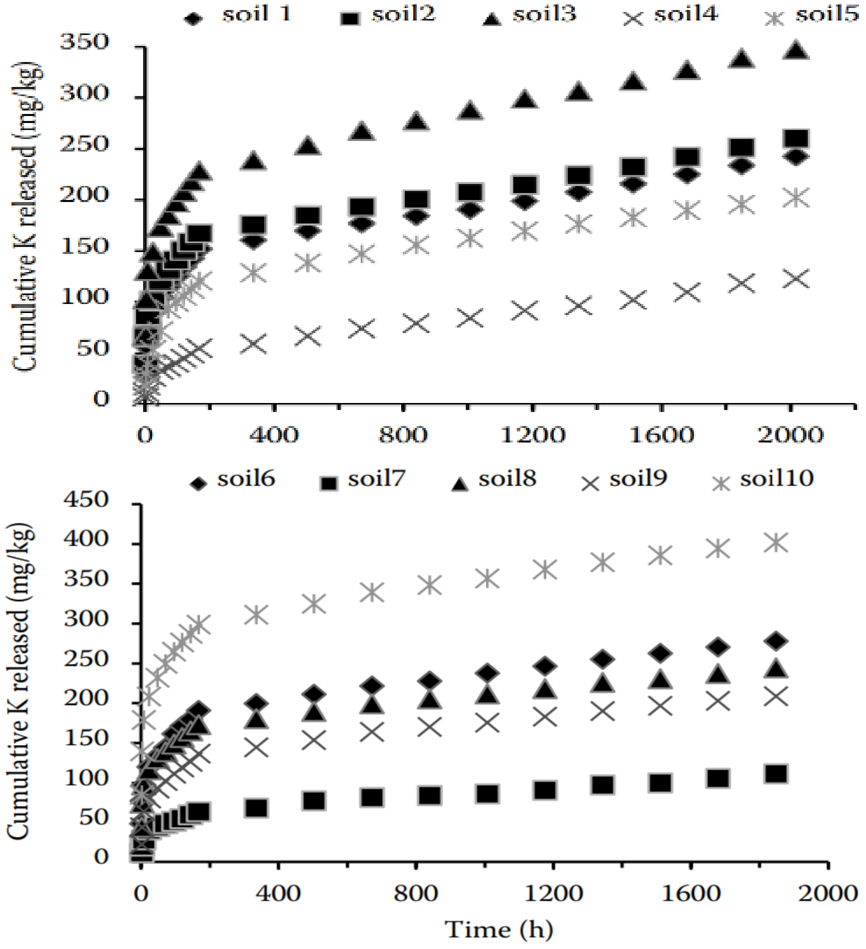


Fig. 2.7 **The cumulative amount of K released with time in soils by successive extractions with 0.01 mol/L CaCl2**

(Source: **Hosseinpur *et al*.,2012**)

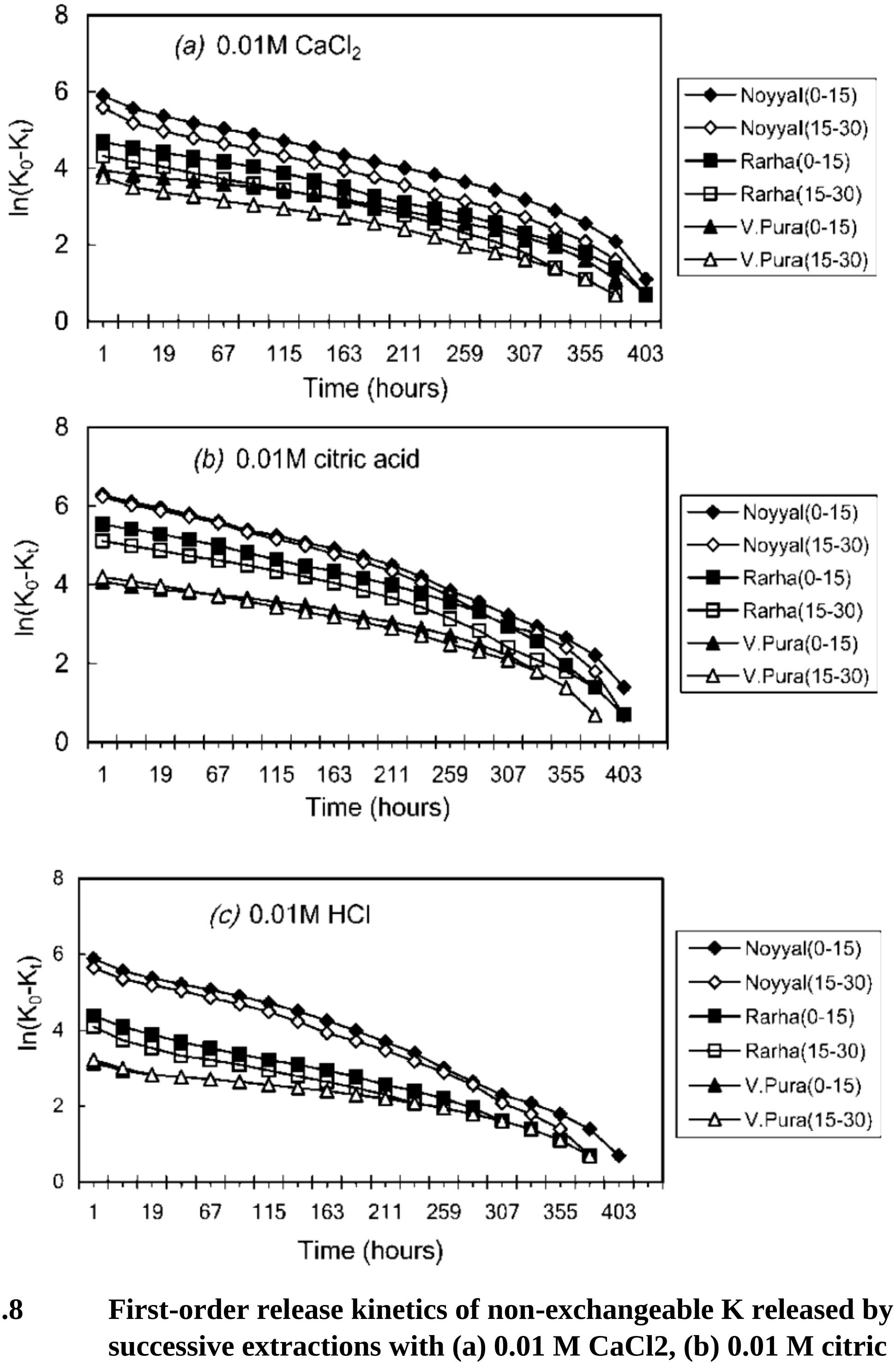


Fig. 2.8 **First-order release kinetics of non-exchangeable K released by successive extractions with (a) 0.01 M CaCl2, (b) 0.01 M citric acid, and (c) 0.01 M HCl media of extraction.**

(Source: **Srinivasarao *et al*., 2007**)

2.6 Future scope of K-bearing minerals as fertilizers for crop cultivation

Modern intensive agriculture gives rise to remarkable depreciation of potassium due to crop removal without balancing with K fertilizer; modern intensive agriculture results in a large drop in soil K status. Most of the K- bearing mineral ores and their processing are confined to some countries like Canada, Russia, Belarus, Germany, Brazil, Chile, Spain, China, the USA, Israel, Jordan, the UK, and Ukraine. India doesn't manufacture any potassium fertilizer, rather it depends completely on foreign countries for the import of potassium fertilizers. So, in emerging countries like India, commercial K fertilizer self-sufficiency is a serious issue. Therefore, alternative sources of K in developing countries where commercial K fertilizers are imported for the agricultural purpose have a bright future. There are certain low-grade but indigenous K-bearing mineral resources that could be used instead of the pricey imported K fertilizers.

Commercial K fertilizers are mass-produced from a variety of minerals that are high in K. Clay minerals in soils and rocks, as well as salt deposits in the ocean from the crystallization of K salts in the dry sea, are the main economic sources of K around the world. K-bearing minerals mostly occur in the sedimentary form like chlorides, and sulphates. Sylvite, carnallite, langbeinite, nitre, polyhalite, and kainite are the minerals most typically utilized in the commercial synthesis of K fertilizers.

According to data of FAO regarding world fertilizer trends (Table 2.3) and outlook to 2022 potassium fertilizer, demand of the world is increasing continuously from the year 2016 to 2022. About 90% of the world's potassium minerals is used in the production of fertilizer and a very less portion is used for other purposes like medicine, cosmetics, explosives, etc.

Mineral salts rich in potassium concentration satisfies the K demand for crop production **(Fixen and Johnston, 2011)**. Indeed, in Indian agriculture, K fertilizers have played a crucial role to achieve and maintain food grain self-sufficiency. Demand is rising every year but the earlier known reserve of potash is constant and limited and developing countries like India has to completely depend on the import of potassic fertilizers which causes large capital investment for importing fertilizers about Rs.1000/- crores per year, with an extra burden of 300/- crores in government subsidies to the agriculture sector for potash fertilizers **(Rakesh *et al.*, 2020)**. Hence it becomes very important to look for alternative sources which can be exploited as a substitute for existing fertilizers. Glauconite, a potassium-rich mineral, has been identified as an indigenous alternative source of potassium in order to reduce reliance on imported K fertilizers. **Karimi *et al*. (2012)** studied Glauconite sandstone as a potential K fertilizer for olive plants. He demonstrated that potassium oxide content in glauconite sandstone is 2.24% and is liable to release potassium in soil solution, and therefore can be used as an alternative source of fertilizers.

Glauconite is found in India amalgamated with sand/sandstones, shale, marl, and other minerals. The deposits are substantially developed in the regions of Son Valley region of Uttar Pradesh and Madhya Pradesh. Glauconitic sandstone has been discovered in various nations throughout the world, including North America, Australia, Belgium, the United Kingdom, and Russia **(Amorosia et al. 2007)**. Rajasthan has a 90% of mineral reserves (**Mohnot *et al.*, 2005**, Central Mining Research Institute; First Indian Mineral Congress, ISM, Dhanabad, Feb. 28- March 1, 2005) in the country and has a potash deposit of approximately 2,400 million tonnes, which is four times the global reserve. Potash reserves of about 133 million tonnes have been found in the Satpura block of Hanumangarh. The Nagore-Ganganagar basin, which includes sections of Sriganganagar, Hanumangarh, and Bikaner districts, has been recognized as having the most deposits. India has the largest deposition of an indigenous glauconite sandstone and has huge potential to develop to slow releasing K fertilizer near future.

Table 2.3 World and regional potassium supply, demand, and balance 2016-2022 (thousand tonnes K_2O)

Potassium	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
World							
Capacity	54638	58455	61951	62055	63467	63513	64553
Supply capability	44177	46284	49422	51373	52752	53664	54147
Other uses	5572	5752	5876	5993	6112	6237	6363
Available for fertilizer	38605	40532	43546	45380	46640	47427	47834
Fertilizer demand	35434	36349	37 171	37 971	38 711	39 473	40 232
Potential balance	3171	4183	6375	7409	7929	7954	7602

(Source: **FAO**-World fertilizer trends and outlook to **2022**)

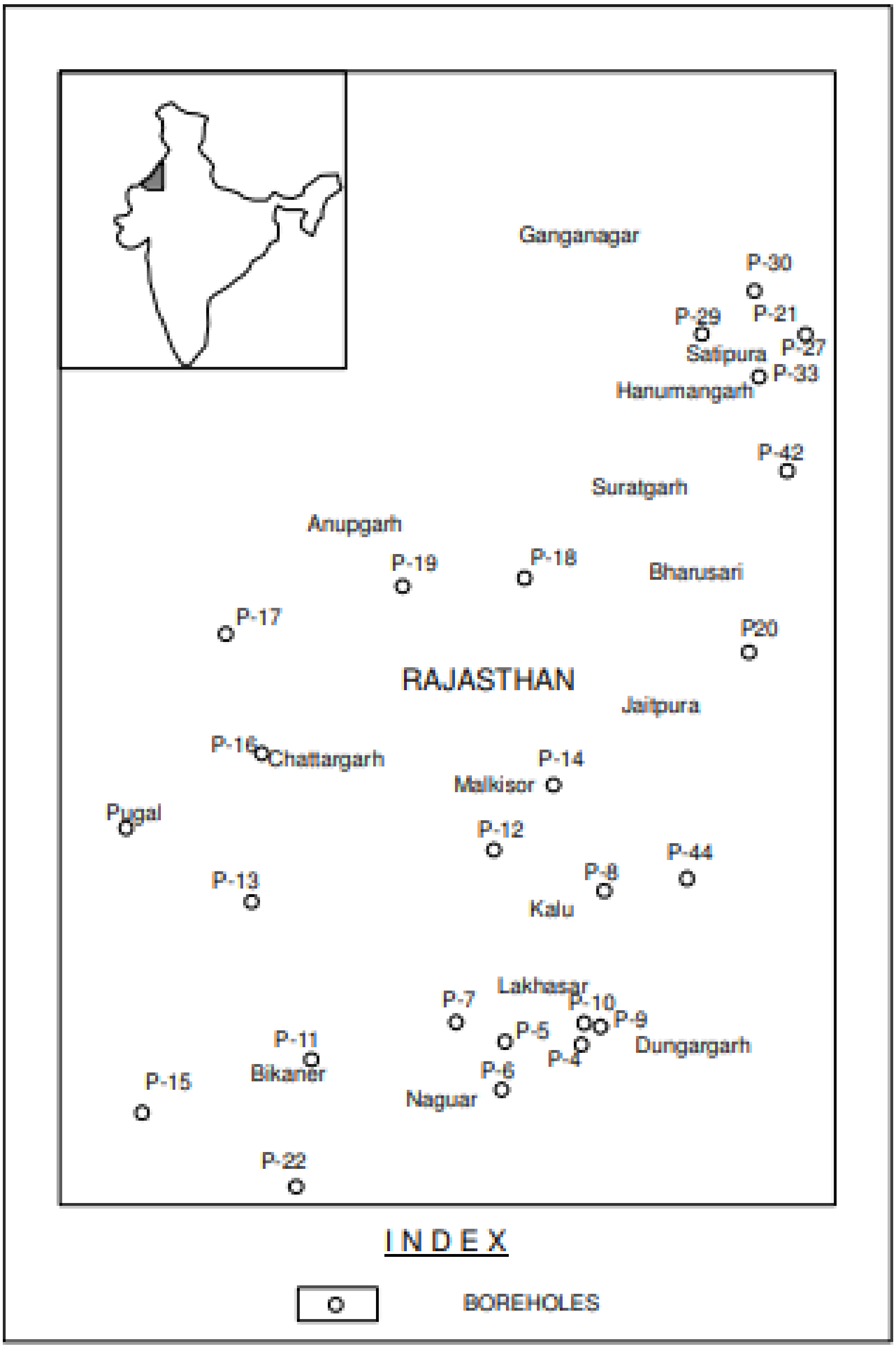


Fig. 2.9 Map of potash-bearing minerals exploration in Rajasthan, India

(Source- **Mohnot *et al*.**,2005, Central Mining Research Institute; First Indian Mineral Congress, ISM, Dhanbad, Feb. 28- Marcqh 1, 2005)

Chapter III

MATERIALS AND METHODS

The present study entitled **"Potassium release in soil amended with potassium bearing minerals"** involved the collection and characterization of soil followed by a laboratory incubation experiment for up to one and half months with the amendment of potassium bearing minerals in the alluvial soil in Varanasi, Uttar Pradesh in the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University.

3.1 Description of the site of soil collection and the experiment

The soil for this experiment was collected from the Agricultural Research Farm of Banaras Hindu University, Varanasi (Plate 3.1). This agricultural farm is located in the southern most part of Varanasi, Uttar Pradesh, India and nearer (4.0 km) to the main stream of river Ganga and the Western ban of the river, i.e. the Gangetic alluvial plain of Varanasi district, Uttar Pradesh.

3.1.1 Physiographic situation

Varanasi district is located at an elevation of 80.71 meters (264.8 feet) from mean sea level (MSL) and the district is situated in the centre of the Gangetic plain of North India, in the Eastern part of the state of Uttar Pradesh, along the left crescent-shaped bank of the Ganges. This agricultural farm of the Banaras Hindu University is located with the GPS coordinates of 25^{0}164.3608"N (Latitude) and 82^{0}59 '25.7784"E (Longitude). It is an Indo-Gangetic alluvial plain in the semi-arid to sub-humid climate zone of Northern India. The district is surrounded by district St. Ravidas Nagar in the East, Chandauli in the West, Jaunpur in the North and Mirzapur district in the South.

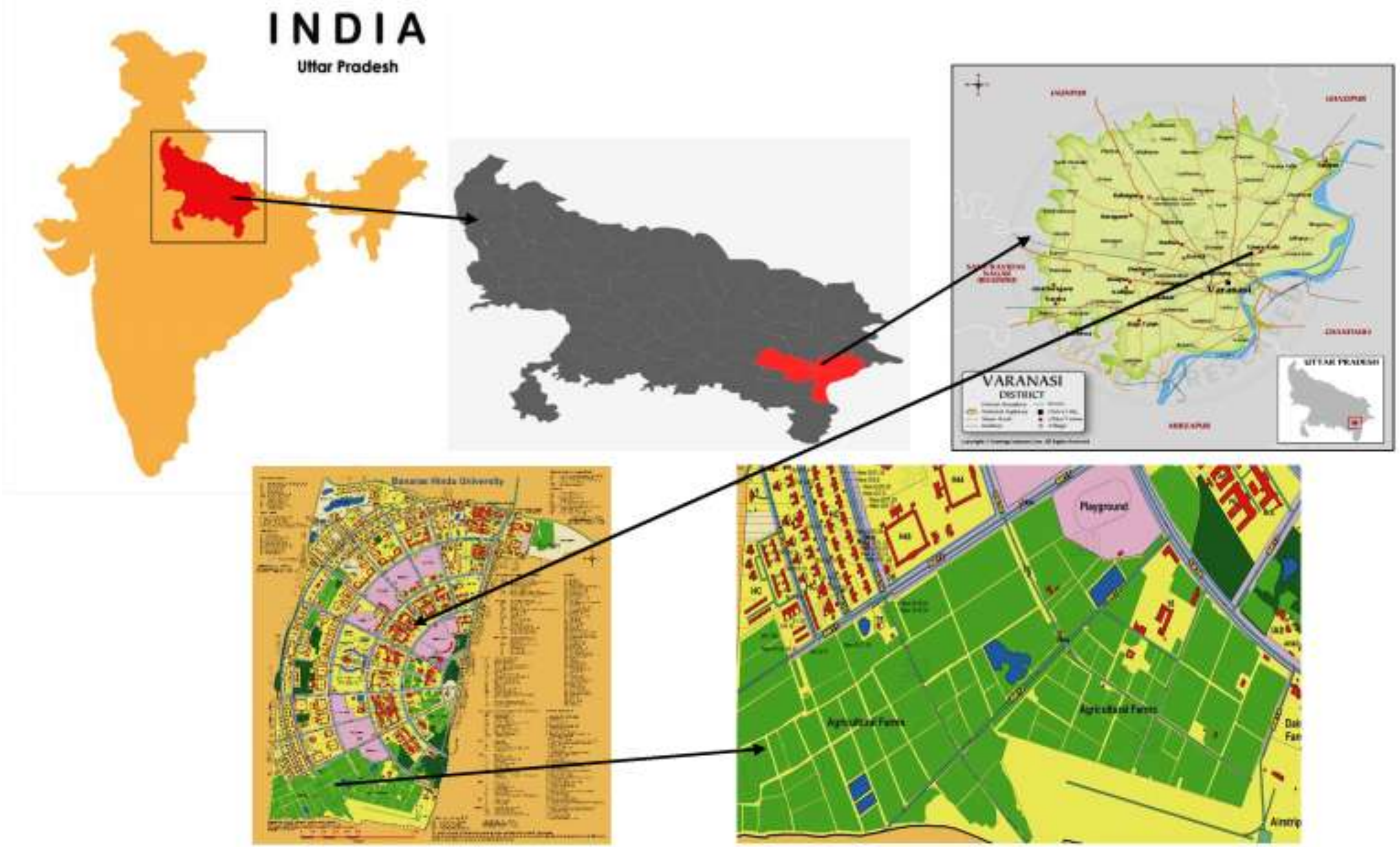


Plate 3.1 Location of the soil sample under study

Plate 3.2 Soil sampling location in Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University

Table 3.1 Weekly meteorological data of Varanasi during the year of experiment (April, 2021- March, 2022)

Week No.	Month & Date	Rainfall mm	Temperature ^{0}C		R.H. %		Wind	Sunshine hours	Evaporation mm
			MAX	MIN	Morn.	Even	Speed km/hr		
14	Apr 02-08 2021	0.0	38.8	18.9	74	20	3.4	6.5	6.3
15	09-15	0.0	35.3	20.2	60	25	2.7	2.9	6.9
16	16-22	0.0	37.3	22.1	58	38	2.5	6.0	6.4
17	23-29	0.0	40.7	20.7	56	30	3.9	9.8	4.9
18	30-06	0.0	38.9	23.7	54	46	5.7	5.2	6.7
19	May 07-13	10.2	36.1	24.5	80	60	3.5	6.4	6.3
20	14-20	77.3	37	23.7	65	65	4.8	4.1	6.3
21	21-27	4.2	33.9	24.1	55	40	3.4	6.2	6.0
22	28-03	48.6	33.8	23.8	60	35	5.0	4.8	4.2
23	June 04-10	1.6	36.9	27	71	55	4.0	6.2	4.6
24	11-17	196.6	34.2	25.8	91	71	6.9	0.0	2.9
25	18-24	456.7	32.9	25.3	94	86	3.8	1.2	2.4
26	25-01	16.4	34.6	26.8	87	71	4.2	2.7	3.3
27	July 02-08	25.6	36	27.2	83	61	3.9	4.0	4.8
28	09-15	1.2	35.2	26.7	85	65	4.2	7.1	5.6
29	16-22	181.2	34.3	26.1	88	73	4.5	4.2	4.5
30	23-29	338	33.6	25.4	91	74	3.1	4.5	3.4
31	30-05	59	32.7	25.2	90	79	3.9	3.5	3.6
32	Aug 06-12	63.8	32.3	26.1	92	80	3.4	3	3.2
33	13-19	0.8	34.9	26.9	90	72	2.6	5.4	3.6
34	20-26	91	33.7	26.0	91	74	3	4.8	3.6
35	27-02	59.5	34.3	23.6	90	68	3.7	5.8	3.3
36	Sep 03-09	31.3	32.9	25.0	91	77	3.7	5.7	3.1
37	10-16	199.8	31.7	23.1	93	75	6.3	4.6	3.0
38	17-23	34	32.2	22.8	95	88	2.4	5.6	2.4
39	24-30	38.8	32.6	25.5	92	81	3.8	5.8	3.6
40	Oct 01-7	46.4	31.9	24.4	93	73	3.3	5.9	2.5
41	08-14	0.0	34.4	23.4	92	61	0.9	7.6	3.0

Table 3.1- Weekly meteorological data of Varanasi during the year of experiment (April,2021- March, 2022)

Week No.	Month & Date	Rainfall mm	Temperature ^{0}C		R.H. %		Wind Speed km/hr	Sunshine hours	Evaporation mm
			MAX	MIN	Morn.	Even			
42	15-21	74.3	33.0	23.1	96	70	2.9	6.3	3.0
43	22-28	0.0	31.8	18.9	93	53	1.2	8.2	2.9
44	29-04	0.0	30.7	14.9	94	46	0.6	8.6	2.3
45	Nov 05-11	0.0	29.7	14.0	95	54	0.6	6.7	1.8
46	12-18	0.0	28.5	13.5	96	48	0.4	6.5	1.9
47	19-25	0.0	28.7	12.2	90	40	1.0	7.2	1.8
48	26-02	0.0	26.7	10.6	97	51	0.4	5.4	1.2
49	Dec 03-09	0.0	26.8	12.8	97	54	0.6	4.2	1.2
50	10-16	0.0	24.6	8.6	94	44	0.5	5.4	1.2
51	17-23	0.0	22.3	7.2	91	53	1.1	6.0	1.3
52	24-31	8.6	21.9	10.0	97	72	1.0	3.1	0.8
1	Jan 1-7 2022	1.2	19.2	8.8	98	75	0.9	3.3	0.6
2	8-14	5.4	22.1	11.8	96	74	1.4	1.6	0.9
3	15-21	0.0	18.5	6.7	93	70	1.6	2.2	1.2
4	22-28	49.0	20.0	9.8	94	68	3.1	3.4	1.7
5	29-04	4.3	22.7	8.6	94	61	3.7	7.2	1.9
6	Feb 05-11	0.0	22.6	9.6	94	57	2.9	5.7	2.0
7	12-18	0.0	25.0	7.9	92	47	2.6	9.6	2.7
8	19-25	0.3	26.7	12.3	90	59	3.7	8.7	3.2
9	26-04	0.4	28.6	12.5	95	53	1.9	8.4	2.9
10	Mar 05-11	0.0	29.7	13.5	89	54	2.4	9.4	3.5
11	12-18	0.0	32.9	16.6	89	53	2.4	8.9	4.1
12	19-25	0.0	36.5	19.3	85	49	2.3	8.7	4.6
13	26-01	0.0	38.0	18.6	79	39	3.1	9.4	5.9

Source: Department of Agronomy, Meteorological data recording centre, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi-221005

3.1.2 Climatic Conditions

Varanasi is a semi-arid to sub-humid climate with a moisture deficit index of 20-40%. May and June are the hottest months with maximum temperatures ranging from 38^0C to 46^0C. However, the cold period starts between November to January with a minimum temperature varying from 5^0 to 10^0C. The onset of monsoon in the region is generally the third week of June which lasts up to the end of September or sometime extends upto the first week of October. The average amount of annual precipitation is 1100mm. A lot of rain (rainy season) falls in the months are June, July, August and September; 80-85% is received from June to September. The relative humidity is about 68% which raise to 90% during the wet season and goes down to 30% during the dry season. The meteorological data of the experimental year, i.e April, 2021 to March, 2022 was available from the meteorological observatory, Institute of Agricultural Sciences, Agricultural Research Farm (Table 3.1), Department of Agronomy, Banaras Hindu University, Varanasi.

3.1.3 Site of the experiment

The laboratory soil incubation experiment was carried out in the Department of Soil Science & Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India.

3.2 Soil Sampling and Processing

The soil for the experiment was collected from (Plate 3.1) the field allotted for "ICAR-All India Co-ordinated Research Project on Pigeonpea," Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. This ICAR-AICRP project on pigeonpea is supervised by the Department of Genetics & Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University.

After collection of soil from farm, the soil was then air dried, grinded, sieved (by 2mm sieve) and stored in plastic drum. For characterization of the collected soil, the physical, chemical and electrochemical properties of the processed soil were determined by standard producers (Piper, 1966; Jackson, 1973, Black, 1965 and Page *et al.*, 1992)

3.3 Analysis of soil

The physical and chemical properties of initial soil samples were determined in the laboratory by following standard processes (Page,1991).

3.3.1 Soil Physical Properties

3.3.1.1 Soil Colour

Soil colour was determined with the help of the Munsell soil colour chart (1994) which was created by Professor Albert H. Munsell and was adopted by the United States Department of Agriculture (USDA) as the official colour system for soil research n the 1930s.

3.3.1.2 Water holding capacity

The water holding capacity of the soil was measured in the laboratory using the Keen-Raczkowski box (Black, 1965).

3.3.1.3 Bulk density and Particle density

The bulk density and particle density of the soil sample were determined in the laboratory using the pycnometer bottle (Black, 1965).

3.3.1.4 Porosity

The pore space or the void space of a soil is the portion of the volume of soil occupied by soil air and soil water. As the soil is a porous system, the percent pore space of soil was calculated from data of bulk density and particle density. The porosity of soil was determined by using the following equation:

$$P = \left(1 - \frac{d_b}{d_p}\right) \times 100$$

Where, P is the porosity of the soil, d_b is the bulk density of the soil and d_p is the particle density of the soil.

3.3.1.5 Soil particle distribution and soil texture

Particle sizes of soil were determined as described by Bouyoucos (1927) using the soil hydrometer method and soil textural class was determined using USDA textural triangle.

Processed air-dried 50g soil was weighed into a 250 mL tall neck beaker. 60mL of 6% H_2O_2 (Hydrogen peroxide) and 40mL distilled water were added and stirred vigorously for 10 minutes on water bath (100^0C). After 24 hours, the soil-water suspension was transferred into a cylinder and made up to 1000mL by distilled water and then shaken soil-water system vigorously for 5 minutes using a plunger. Soil hydrometer was placed in suspension and reading was taken exactly after 4 minutes and 2 hours. Sand, silt, and clay present in soil were calculated and soil textural class were determined by putting the values in USDA textural triangle.

3.3.2 Soil electrochemical and chemical properties

3.3.2.1 Soil pH

The pH of the soil was measured at 1:2.5 (Soil: Water) suspension with the help of a glass electrode digital pH meter (Black, 1965).

3.3.2.2 Soil Electrical Conductivity

The soil water suspension was prepared in the 1:2.5 (Soil: Water) ratio. The filtrate of the suspension was used to determine of electrical conductivity of soil using the Electrical conductivity (EC) meter (Black,1965).

3.3.2.3 Cation Exchange Capacity

CEC of the soil sample was determined by centrifuge method through leaching the soil successively three times with sodium acetate solution (pH 8.2) for replacement of exchangeable cations with sodium ions (Na^+). Excess salts are washed away by alcohol and the adsorbed sodium ion (Na^+) were replaced with ammonium ions ($NH4^+$) by using ammonium acetate solution. The release of sodium ions (Na^+) in solutions is measured by using the flame photometer. The CEC of the soil was calculated as:

$$CEC\ (cmol\left(\frac{p^+}{kg}\right) = \frac{Concentration\ of\ Na^+\ in\ extract\ \left(\frac{mg}{L}\right) \times volume\ of\ the\ extract\ (mL)}{Weight\ of\ soil\ \times 23} \times\ 100$$

3.3.2.4 Soil organic carbon

The chromic acid wet digestion method developed by Walkley and Black (1934) was used in the estimation of organic carbon and organic matter in the soil.

3.3.2.5 Plant Available Nitrogen

Plant available nitrogen was estimated by using alkaline permanganate method (Subbiah and Asija, 1956).

Five gram air dried processed soil was weighed and transferred to a Kjeldhal distillation quartz glass tube (500mL). 20 mL of distilled water was added to the Kjeldhal tube and 1mL of liquid paraffin (hydrocarbon) added to control frothing during distillation. Two glass beads were put in tube to prevent bumping. 25mL of 0.32 potassium permanganate solution and 25mL of 2.5% NaOH solution were sequentially added for distillation. The contents were distilled in distillation system (Kjeltron, Tulin equipment, Chennai, Tamil Nadu) in a steady state and the liberated NH_3 was collected after condensation in 100mL conical flask containing 20mL of boric acid solution with mixed indicator (0.099g of bromocresol green + 0.066g of methyl red in 100mL ethyl alcohol). Distillation was continued for about 10 minutes or until 100mL of distillate was collected in a conical flask. The ammonia collected was titrated against 0.02N sulphuric acid. From the titre value of the soil sample and blank, the available nitrogen content in the soil was calculated.

3.3.2.6 Plant available phosphorus

The plant-available phosphorus was estimated by following Olsen's method. Soil sample was extracted with 0.5 N sodium bicarbonate ($NaHCO_3$) having a pH of 8.5 in a 1:20 ratio (Soil: $NaHCO_3$) by shaking the mixture for 30 minutes, in presence of activated charcoal, i.e. Darco-G (Olsen *et al*., 1954). The colour of extracted filtrate solution was developed by ascorbic acid blue (Wertanabe and Olsen, 1965) and the intensity of the colour was estimated by the spectrophotometer method.

3.3.2.7 Plant available Potassium

Plant available potassium was determined by extracting the soil with 1 N neutral ammonium acetate solution by shaking the mixture of soil and ammonium acetate solution on a mechanical shaker for 5 minutes. The potassium concentration in the filtrate solution was measured using a flame photometer (Systronics India Pvt. Ltd, Model 130, Ahmedabad, Gujarat) as described by Hesse (1971).

3.3.2.8 Plant Available Sulphur

Plant available sulphur in soil sample was determined by extracting the soil sample with 0.15% $CaCl_2$ solution and determining the available sulphur by the turbidimetric method described by Palasker *et al*., (1950). Turbidity was developed in soil extracting (0.15% $CaCl_2$) filtrate by using $BaCl_2$ and gum acacia (0.1% solution) and the turbidity of the solution was measured by spectrophotometer (Labtronics, Model: LT-39, Panchkula, Haryana).

3.3.2.9 Available Calcium and Magnesium

Plant available total Ca^{+2} and Mg^{+2} of the initial soil sample was determined by complexometric titration. Five grams of soil sample was taken in 100mL conical flask and saturated with 1N neutral ammonium acetate solution and shaken for 30 min. on the mechanical shaker. The soil suspension was filtered through Whatman No. 1 filter paper in a volumetric flask. Then total Ca^{+2} and Mg^{+2} was determined by taking a 5mL aliquot from the extract in a 100 ml conical flask. The pH was adjusted by adding 15 mL of buffer solution (NH_4OH + NH_4Cl) solution and then 10 drops of erichrome black T indicator solution containing $NH_2OH.HCl$ & triethanolamine was added to it and titrated against standard EDTA (0.01N) solution until the colour changes from wine red to blue.

3.3.2.10 Available Calcium

Calcium was determined by complexometric titration. 5 mL aliquot of 1N neutral ammonium acetate extract of soil sample was taken in 100 mL conical flask. To this 5 mL of 10%, NaOH solution and 50 mg murexide indicator powder were added. The solution was titrated against 0.01N EDTA solution till the colour changes from pink to purple.

3.4 Soil Incubation

3.4.1 Incubation for potassium (K^+) release in soil

The release of potassium in soil from potassium-bearing minerals was conducted in the laboratory (Plate 3.3) incubation method. Well processed and air-dried soil weighed 250 g were taken in 162 plastic containers individually and then 9 treatments of potassium from four mineral sources of K having 3 replications were mixed thoroughly into these plastic containers. The soil in plastic containers was maintained at field capacity (50% water holding capacity) by periodical addition of deionized water throughout the incubation period (*viz*. 5, 15, 30, 45, 60, and 90 days). The laboratory incubation study (Table-3.2) was done at room temperature (20 ± 5^0 C) at 1-atmosphere pressure and moisture at field capacity.

After 5, 15, 30, 45, 60, and 90 days of the incubation period of potassium-bearing minerals in the soil, released potassium ($K^{+)}$ were extracted cumulative release of potassium in (K^+) and then analyzed. Soil moisture content in samples was considered during the calculation of cumulative release potassium (K^+) in the soil.

Plate: 3.3 Laboratory incubation experiment

3.4.2 Potassium bearing minerals

In order to study the cumulative release pattern potassium (K^+) from soil amended potassium bearing minerals, the four sedimentary natural minerals were taken. Among the four natural minerals, three minerals were taken as the source of high grade potassium minerals, generally formed as evaporite sedimentary minerals viz. Sylvinite (KCl), Nitre/Saltpeter (KNO_3) and langbeinite [$K_2Mg(SO_4)$] i.e chloride, nitrate and sulphate salts of potassium. All these minerals, i.e Cl^-, NO^{3-}, and SO_4^{2-} of K^+ are generally exported from foreign countries. Fourth mineral as a source potassium fertilizers was taken as mica group of phyllosilicate minerals, i.e. glauconite. Glauconite is a typical indigenous mineral occurs in the Son valley in Madhya Pradesh and Uttar Pradesh anda huge amount in Rajasthan, particularly in Nagaur- Ganganagar district: 4.6 MT). Glauconite is considered as low grdae potassium bearing minerals (i.e. 6-8% K_2O) and highly insoluble in water.

3.4.2.1 Sources of Potassium bearing minerals

The high-grade K bearing minerals, i.e. sylvinite (processed as MoP) and niter (saltpeter) were purchased from standard companies through online (i.e amazon.in and flipkart). The commercial langbeinite (K-mag) was collected from The Mosaic Company. The glauconitic sandstone of Son valley was collected from Department of Geology (Prof. B.P. Singh, HOD), Institute of Science, Banaras Hindu University.

S.No.	Name of the minerals	Sources of K-bearing minerals
1.	**Sylvinite** (as MoP: processed mineral)	Shivi Products (Marketing: Flipkart)
2.	**Niter** (Peter salt/Saltpeter)	Kalmi Shora Neeraj Traders E-221, Purani Pasrat, Jhansi, Uttar Pradesh (2824002) (Marketing: amazon.in)
3.	**Langbeinite** (K-Mag)	The Mosaic Company Mosaic India, Tower 8C, 11th floor, DLF cyber city, Gurgaon, Harayana, India
4.	**Glauconite** (Sandstone of Son valley)	Department of Geology, Institute of Science, Banaras Hindu University, Varanasi (221005)

3.4.3 Treatment of potassium-bearing minerals in the soil

S.No.	**Treatment**	**Treatment Notation**	**Description of the treatment**
1.	T_1	C	Control (without addition of K-bearing mineral)
2.	T_2	P_1	Saltpeter (1.48g kg^{-1} of soil)
3.	T_3	P_2	Saltpeter (2.96g kg^{-1} of soil)
4.	T_4	L_1	Langbeinite (3.04g kg^{-1} of soil
5.	T_5	L_2	Langbeinite (6.08g kg^{-1} of soil)
6.	T_6	S_1	Sylvinite (2.08g kg^{-1} of soil)
7.	T_7	S_2	Sylvinite (2.16g kg^{-1} of soil)
8.	T_8	G_1	Glauconite (11.12g kg^{-1} of soil)
9.	T_9	G_2	Glauconite (22.24g kg^{-1} of soil)

C=Control, P= Saltpeter, L= Langbeinite, S= Sylvinite, G= Glauconite

The amount of soil amendment of K-bearing minerals for the investigation of the pattern of cumulative release of K in soil the dose of K for the cultivation banana i.e. 1500 kg K_2O/ha (Sathia Moorthy and Jeyabaskaran, 2010) was considered. Considering the percent content of K_2O in different minerals, finally single (1) and double doses (2) of K_2O were calculated. The percent of K_2O in soil amended saltpeter (P), langbeinite(L), sylvinite(S) and glauconite minerals (G) were 46, 22, 62, and 6, respectively.

The minerals after collection from commercial houses and research laboratory, were grinded in powder forms and thoroughly mixed with air dried soil in desired amount. The single and double doses of saltpeter (P) were 0.370g and 0.740g per 250g of soil, 0.760g and 1.520g per 250g of soil for langbeinite, 0.270g and 0.540g per 250g soil for sylvinite minerals, respectively. The single and double doses for low grade K-bearing minerals, glauconite were comparatively higher, i.e. 2.78g and 5.56g per 250g of soil, respectively.

Table 3.1 Treatment details at different stages of soil incubation

Treatments	**Incubation Period (Days)**																	
	5			**15**			**30**			**45**			**60**			**90**		
	R_1	**R_2**	**R_3**	**R_1**	**R_2**	**R_3**	**R_1**	**R_2**	**R_3**	**R_1**	**R_2**	**R_3**	**R_1**	**R_2**	**R_3**	**R_1**	**R_2**	**R_3**
T_1	C_1R_1	C_1R_2	C_1R_3	C_1R_1	C_1R_2	C_1R_3	C_1R_1	C_1R_2	C_1R_3	C_1R_1	C_1R_2	C_1R_3	C_0R_1	C_1R_2	C_1R_3	C_1R_1	C_1R_2	C_1R_3
T_2	P_1R_2	P_1R_2	P_1R_3	P_1R_1	P_1R_2	P_1R_3	P_1R_1	P_1R_2	P_1R_3	P_1R_1	P_1R_2	P_1R_3	P_1R_1	P_1R_2	P_1R_3	P_1R_1	P_1R_2	P_1R_3
T_3	P_2R_1	P_2R_2	P_2R_3	P_2R_1	P_2R_2	P_2R_3	P_2R_1	P_2R2	P_2R_3	P_2R_1	P_2R_2	P_2R3	P_2R_1	P_2R_2	P_2R_3	P_1R_1	P_1R_2	P_1R_3
T_4	L_1R_1	L_1R_2	L_1R_3	L_IR_1	L_1R_2	L_1R_3	L_1R_1	L_1R_2	L_1R_3	L_1R_1	L_1R_2	L_1R_3	L_1R_1	L_1R_2	L_1R_3	L_1R_1	L_1R_2	L_1R_3
T_5	L_2R_1	L_2R_2	L_2R_3	L_2R_1	L_2R_2	L_2R_3	L_2R_1	L_2R_2	L_2R_3	L_2R_1	L_2R_2	L_2R_3	L_2R_1	L_2R_2	L_2R_3	L_2R_1	L_2R_2	L_2R_3
T_6	S_1R_1	S_1R_2	S_1R_3	S_1R_1	S_1R_2	S_1R3	S_1R_1	S_1R_2	S_1R_3	S_1R_1	S_1R_2	S_1R_3	S_1R_1	S_1R_2	S_1R_3	S_1R_1	S_1R_2	S_1R_3
T_7	S_2R_1	S_2R_2	S_2R_3	S_2R_1	S_2R_2	S_2R_3	S_2R_1	S_2R_2	S_2R_3	S_2R_1	S_2R_2	S_2R_3	S_2R_1	S_2R_2	S_2R_3	S_2R_1	S_2R_2	S_2R_3
T_8	G_1R_1	G_1R_2	G_1R_3	G_1R_1	G_1R_2	G_1R_3	G_1R_1	G_1R_2	G_1R_3	G_1R_1	G_1R_2	G_1R_3	G_1R_1	G_1R_2	G_1R_3	G_1R_1	G_1R_2	G_1R_3
T_9	G_2R_1	G_2R_2	G_2R_3	G_2R_1	G_2R_2	G_2R_3	G_2R_1	G_2R_2	G_2R_3	G_2R_1	G_2R_2	G_2R_3	G_2R_1	G_2R_2	G_2R_3	G_2R_1	G_2R_2	G_2R_3

C= Control, P= Saltpeter (Niter), L= Langbeinite (K-Mag), S= Sylvinite (MoP), G= Glauconite, R_1= 1st Replication…… R_3= 3rd Replication

3.4.4 Method of Laboratory Incubation Experiment

The purpose of the experiment was to assessment of cumulative potassium (K^+) release pattern and the kinetics of K-release of nonexchangeable potassium (K^+) in farm soil from high grade water-soluble K-bearing minerals (*viz*. saltpeter, langbeinite and sylvinite) and low-grade water insoluble phyllosilicate K-bearing mineral (glauconite).

The incubation experiment was carried out under laboratory condition, i.e at laboratory temperature 20.3±3^0C, 1 atmospheric pressure and under field capacity soil moisture condition. The laboratory temperature was recorded everyday at 10.00 AM and the weekly record of the mean temperature of the laboratory from 1st December, 2021 to 1st March, 2022 was calculated (Table 3.2) for the variation of temperature during 90 days incubation period. The soil under laboratory incubation was maintained field capacity moisture by regularly watering of the soil in container with treatment by calculating the moisture loss. At the initial stage of incubation the soil moisture was given by calculating 60% of the water holding capacity (WHC) of soil.

250g processed air-dried soil was taken in plastic cup of capacity 250cc. Two doses (recommended dose of K in banana crop and double the recommended dose K in banana) of four minerals, i.e. 8 treatment (T_2 to T_9) and one control (T_1) were applied by calculating the mineral materials in grinded form. The doses of the treatment were as, T_1 (Control, i.e. without any mineral amendment in soil, T_2 (Saltpeter @1.48g kg^{-1}), T_3 (Saltpeter @ 2.96 g kg^{-1}), T_4 (langbeinite @ 3.04 mg kg^{-1}), T_5 (langbeinite @ 6.08g kg^{-1}), T_6 (sylvinite 1.08g kg^{-1}), T_7 (sylvinite @ 2.16g kg^{-1}), T_8 (glauconite @ 11.12g kg^{-1}), T_9 (glauconite @ 22.24g kg^{-1}). The calculated grind powder form of all the minerals were individually weighted and then mixed with 250g of soil. Water was added i.e 60% WHC after mixing the mineral in the soil. The period of incubation (Plate 3.3) was 5, 15, 30, 45, 60 and 90 days. The total of 162 (treatment: 9 × replication: 3×6 period of incubation) incubated cups were maintained for the experiment. After the designated incubation period, the soil samples were extracted for K^+ analysis.

Table 3.2 Weekly mean laboratory incubation temperature (^{0}C)

Week No.	Month & Date	Mean temperature (^{0}C) in laboratory
1.	December 2021, 01-07	23.2
2.	08-14	23.0
3.	15-21	21.0
4.	22-28	20.3
5.	29.04	19.2
6.	January 2022, 05-11	18.6
7.	12-18	18.8
8.	19-25	18.0
9.	26-01	18.7
10.	February 2022, 02-08	19.8
11.	09-15	20.1
12.	16-22	21.2
13.	23-01	22.5
Mean temperature (^{0}C) during incubation: 20.3^{0}C		
Range of temperature (^{0}C): 18.0^{0}C-23.2^{0}C		
Incubation temperature: 20.3±3^{0}C		

3.4.5 Analysis of released potassium (K^+) in soil

The water soluble, exchangeable and non-exchangeable K^+ in soil after incubation schedule were extracted from different minerals amended soil. The kinetics of release pattern of non-exchangeable K^+ in soil due to soil amendment of K-bearing minerals was estimated by the extracting the soil with $CaCl_2$ solution. The procedures for extraction of the different form of K were described separately.

3.4.5.1 Water soluble potassium

After the schedule period of incubation (i.e. 5, 15, 30, 45, 60 and 90 days), 5.0g soil from each incubation cup was directly taken in 100mL conical flask and then 25mL of distilled water was added into the conical flask (soil: water ratio as 1:5). The soil-water suspension was centrifuged (REMI: R-8C) at 4500 rpm (Plate-3.5) for 10 minutes and clear supernatant solution was taken plastic container (30mL capacity) for further analysis. The water-soluble K (K^+) was analysis in flame photometer (Systronics India Pvt.Ltd., Model 130). The calculation in water soluble K (K^+) content was done by subtracting the, moisture content of soil sample. The moisture content in soil sample was determined by gravimetric method using aluminium moisture box and water-air oven (at 105^0C).

3.4.5.2 Exchangeable potassium

The exchangeable or plant available K in incubated soil was estimated by extracting the 5.0g soil with 25mL neutral 1N ammonium acetate (1N NH_4OAc) solution, i.e soil: solution ratio of 1:5. The soil-solution suspension was shaken for 5 minutes in mechanical horizontal shaker for 5.0 minutes. After equilibrium at 5.0 minutes, the soil-solution was filtered immediately through Whatman no. 1 filter paper. The filtrate was taken in plastic container and analysed in flame photometer. The calculation in exchangeable K content was done also by substracting the moisture content of soil sample during extraction.

3.4.5.3 Non-exchangeable potassium

The incubated soil after schedule period was first air dried immediately in laboratory and air-dried sample preserved for further analysis. For the extraction of non-exchangeable K in soil, 2.5g of soil was extracted in 25mL of 1M HNO_3 solution in 100mL conical flask at 180^0C on hot plate for 30 minutes. After 1M HNO_3 extracting the soil-solution suspension was filtered through Whatman no. 1 filter paper in 25mL volumetric flask. Final volume in volumetric flask was made up to 25mL using distilled water. The potassium (K^+) in solution was analysed using flame photometer.

3.4.6 Potassium release kinetics in soil

After incubation, the potassium release kinetics (K^+) in soil was estimated by extracting the soil by 0.01M $CaCl_2$ solution. 2.5g of incubated soil was extracted by 50mL 0.01M $CaCl_2$ solution (1:10) for 30 minutes in mechanical shaker. The potassium (K^+) in filtrates were analysed in flame photometer.

The moisture content in soil was done by gravimetric soil moisture content analysis. During final calculation of the kinetics of K of nonexchangeable K^+ in soil native solution K was also subtracted from cumulative nonexchangeable K^+. Potassium released with time was calculated for potassium release kinetics in soil.

3.4.7 Periodical estimation of soil pH and EC

3.4.6 Analysis of pH

The pH of incubated soils for time intervals of 5, 15, 30, 45, 60, and 90 days were analyzed by using a pH meter. The soil sample with distilled water was taken in a 1:2.5 (Soil: Water) ratio and mixed in a 50ml beaker and shaken for 5 minutes. intermittently for 30 minutes. After that pH soil-water suspension was determined by immersing the electrode of pH meter into it and reading was recorded.

3.4.7 Analysis of EC

The EC of incubated soils of time intervals of 5, 15, 30, 45, 60, and 90 days were analyzed by EC meter by taking soil and distilled water in a 1:2.5 ratio and mixing it with a glass rod for 5 minutes and intermittently for 30 minutes after that the soil suspension was filtered through Whatman filter paper No. 1 and the filtrates were used for the analysis of EC.

3.5 Statistical analysis

Data obtained from the laboratory incubation study were subjected to analysis of variance complete randomized design (CRD) using statistical software IBM SPSS (Statistical Package For The Social Sciences). Significant differences in mean values were identified using Duncan’s Multiple Range Test (DMRT) method at the 0.05 level of significance. All graphs were plotted with the help of Microsoft Office Excel 2016.

Plate 3.4: Mineral materials from commercial houses and from natural system **(A)** Saltpeter packet (Kalmi Shora), **(B)** MOP packet (sylvinite), **(C)** Packet of K-mag (Langbeinite), **(D)** Glauconite layer (from Department of Geology)

Plate 3.5 **Ground materials of K-bearing minerals (A)** Sylvinite (as MoP) **(B)** Salt Peter **(C)** Langbeinite **(D)** Glauconite

Plate 3.6 Laboratory instruments used in the experiment (A) Flame photometer; **(B)** Centrifuge machine; **(C)** Hot-air oven; **(D)** Mechanical shaker

Chapter IV

RESULTS AND DISCUSSION

The present study entitled **"Potassium release in soil amended with potassium bearing minerals"** was performed at the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. In this chapter, an attempt has been made to assess the release of potassium from different potassium-bearing minerals in the soil and also periodical changes in pH and EC of soil. The soil was collected from the field of pulse growing area of Agricultural farm, Institute of Agricultural Sciences, Banaras Hindu University. The incubation experiment of soil treated with K-bearing minerals was conducted in the aboratory at room temperature, at 1 atmospheric pressure and soil moisture at field capacity. The objectives of this incubation study were to investigate the release pattern of potassium from potassium-bearing minerals in the soil and also changes in pH and EC at various periods of incubation (5, 15, 30, 45, 60, and 90 days) in the Inceptisol of Varanasi, Uttar Pradesh. The data collected through the course of the investigation were statistically examined in order to get a valid conclusion. This chapter describes and discusses the findings of the laboratory soil incubation experiment for the duration of December, 2021 to February, 2022.

4.1 CHARACTERIZATION OF SOIL UNDER STUDY

The data pertaining to the physical and chemical properties of experimental soil under laboratory conditions are presented in Table 4.1. From Table 4.1 it was found that the soil used for the experiment of the Agricultural farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, was sandy loam. The physical properties of soil *viz*. bulk density and particle density were in medium-range and the colour of the soil is dark brown (10YR/4/3). The organic carbon content and phosphorus were high in content, potassium was in the medium range, nitrogen was in the low range and sulphur was in the low range. The soil shows neutral pH (7.41) and is low in EC with CEC14.61 cmol (p^+) kg^{-1}. The soil under study was collected from the Gangetic alluvial plain and the soil order is Inceptisol.

Table 4.1 **Physical and Chemical properties of experimental soil under laboratory incubation study**

Parameter	**Value**
Bulk density (Mg m^{-3})	1.21
Particle density (Mg m^{-3})	2.27
Porosity (%)	46.7
Soil Colour (Munsell)	10YR/4/3 (dark brown)
Sand (%)	69.95
Silt (%)	9.60
Clay (%)	20.4
Textural class (USDA)	Sandy loam
Water holding capacity (%)	47.0
pH_w (1:2.5)	7.41
EC (1:2.5) dSm^{-1}	0.236
CEC [cmol(p^+) kg^{-1}]	14.61
Organic carbon (g kg^{-1})	8.1
Organic matter (g kg^{-1})	13.9
Available N (kg ha^{-1})	200.7
Available P (P_2O_5) kg ha^{-1}	44.78
Available K (K_2O) kg ha^{-1}	277.6
Available calcium (meq/100g soil)	7.20
Available magnesium (meq/100g soil)	5.72
Available sulphur (kg ha^{-1})	10.6

Table 4.2 Characteristics of potassium-bearing minerals under study

S.No.	Property	Sylvite	Niter (Saltpeter)	Langbeinite	Glauconite
1.	**Type**	Evaporite (Sedimentary)	Evaporite (Sedimentary)	Evaporite (Sedimentary)	Sandstone (Mica group of minerals) (Silty clayed sedimentary)
2.	**Colour**	Colourless to white with shades of red (due to hematite inclusions)	Colourless to white	Colourless with shades of, pink, red, green, yellow, gray	Olive green to light green (dull green)
3.	**Streak**	White	White	White	Light green
4.	**Chemical formula**	KCl	KNO_3	$K_2Mg_2(SO_4)_3$	$[(K, Na)(Fe^{3+}, Al, Mg)_2(Si, Al)_4O_{10}(OH)_2]$
5.	**Percentage (%) of K_2O**	62 (as Muriate of Potash)	46 (as saltpeter)	22 (as Potassium sulphate)	6 (8-12%) as phyllosilicate
6.	**Tenacity**	Brittle to ductile	Brittle	Brittle	Highly matured hard (brittle pellet)
7.	**Solubility**	Soluble in water	Highly soluble in water	Slowly dissolves in water (280 g L^{-1} at 20^0C)	Insoluble
8.	**Specific gravity (g/cc)**	1.99	2.10	2.83	2.95
9.	**Mohs hardness**	2.0- 2.5	1.5-2.0	3.5-4.0	2.0- 2.5

*Sylvinite is a sedimentary rock and this rock is the mechanical mixture of sylvite (KCl) and halite (NaCl) minerals.

4.2 CHARACTERISATION OF POTASSIUM-BEARING MINERALS UNDER STUDY

The potassium-bearing minerals used in this study are saltpetre, langbeinite, sylvinite (processed form as MOP) and glauconite sandstone from Son valley, Uttar Pradesh. The characterization of K-bearing minerals is presented in **Table 4.2**. These minerals were applied to incubated soil according to the potassium requirement of the banana crop (1500 kg ha^{-1}). Sylvinite is a sedimentary rock consisting of a mixture of halite (NaCl portion) and sylvite (KCl). Sylvinite is one of the most important sources of potash production in North America, Russia, and the UK. The product's chemical composition is Potassium chloride (KCl) with 62% K_2O and 74.4% K. Salt Peter occurs in form of crust on rocks, walls of caves, and also in soils of places like Spain, Italy, Egypt, Iran, and India. The K_2O content is 46% and K is 55.2% and N content is 13%. Langbeinite is a unique geological mineral since it contains three essential nutrients like potassium (K), Magnesium (Mg), and Sulphur (S) for growing plants. It is found only in a few places in the world. It was commercially developed for the first time from underground mines near Carlsbad, New Mexico (USA), in the 1930s. Minerals like sylvinite and saltpeter are readily soluble, langbeinite is sparingly soluble in water and glauconite sandstone is insoluble in water. The colour of saltpeter (niter) is crystal white. The sylvite (one of the components of sylvinite) is white in colour, with shades of red (due to hematite inclusions. The langbeinite mineral is colourless with shades of pink, red, green, yellow and grey. The phyllosilicate glauconite sandstone is olive green (dull green) in colour and of high density (2.95g/cc) materials. The density of sylvinite, saltpeter and langbeinite are 1.99, 2.10 and 2.83 g/cc respectively.

4.3 RELEASE OF POTASSIUM FROM SOIL AMENDED WITH POTASSIUM-BEARING MINERALS

Potassium (K) release in soil plays a very important role in the supply of available K for uptake of plant. Potassium in soil occurs in water-soluble, exchangeable, non-exchangeable and structural forms. Plants first uptake potassium from soil solution which is easily available and after exhaustion of potassium from soil solution, exchangeable potassium are released in available form but further demand of potassium is fulfilled by non-exchangeable form of

Table 4.3 Release of water-soluble potassium (H_2O-K) in soil treated with K- bearing minerals

Treatment	Doses of K-bearing minerals (g/250g soil)	Release of potassium (mg/kg)					
		Period of incubation (Days)					
		5	15	30	45	60	90
T1 (C)	**0.00**	25.06±0.09 **f**	18.80±0.54**g**	12.39±0.22**f**	12.10±0.59 **e**	12.39±0.24**g**	23.56±0.21**g**
T2 (P1)	**0.37**	58.65±3.96 **e**	147.63±1.93**d**	141.23±9.23**d**	119.31±20.59**c**	147.24±5.95**d**	147.24±7.59**d**
T3 (P2)	**0.74**	92.30±4.24**d**	271.96±5.49 **c**	338.44±10.95**b**	345.98±8.78**a**	415.78±12.57**a**	453.37±24.2**a**
T4 (L1)	**0.76**	88.06±6.45**d**	114.45±4.29**f**	90.53±1.34**e**	87.16±3.47**d**	83.37±0.49**f**	129.87±7.35**f**
T5 (L2)	**1.52**	275.88±16.88**a**	297.74±2.37**b**	246.36±15.28**c**	291.77±2.22**b**	245.02±3.22**c**	321.40±17.12**c**
T6 (S1)	**0.27**	127.63±7.60**c**	141.52±2.74**e**	133.22±4.27**d**	129.73±3.80**c**	134.50±2.10**e**	174.98±20.03**e**
T7 (S2)	**0.54**	185.41±8.70**b**	395.03±6.42**a**	362.76±10.47**a**	358.92±12.59**a**	382.39±11.29**b**	428.22±8.94**b**
T8 (G1)	**2.78**	24.95±0.11**f**	19.63±0.30**g**	12.64±0.21**f**	12.44±0.72**e**	12.02±0.60**g**	23.46±0.60**g**
T9 (G2)	**5.36**	47.60±2.17**e**	18.83±0.65**g**	12.77±0.04**f**	11.77±0.37**e**	11.77±0.47**g**	18.45±0.46**g**
Mean		102.84	158.402	150.040	152.134	160.501	191.176
SEm (±)		4.298	1.997	4.590	5.065	3.533	7.331
CD (P=0.05)		12.768	5.933	13.638	15.049	10.496	21.780

C= Control; P= Saltpeter; L= Langbeinite; S= Sylvinite; G= Glauconite

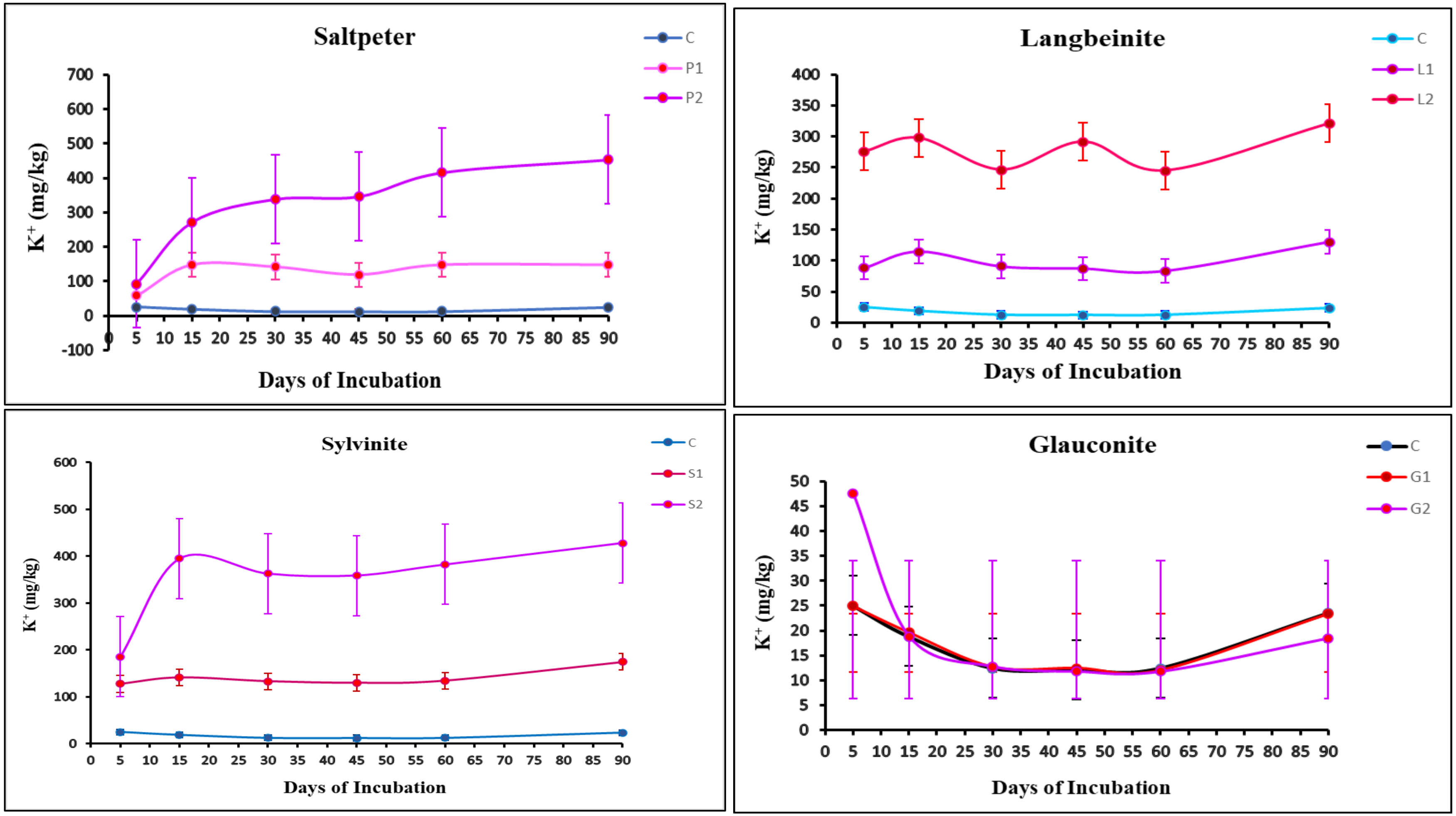


Fig 4.1 Release pattern of water-soluble K^+ (mg of K^+/ kg of soil) in soil treated with K- bearing minerals
(C= Control; P= Salt Peter; L= Langbeinite; S= Sylvinite; G= Glauconite; 1= single dose, 2= double dose)

potassium. In this chapter the successive potassium release patterns (5, 15, 30, 45, 60, and 90 days intervals) in water-soluble potassium, exchangeable potassium, and non-exchangeable K from potassium-bearing minerals (sylvinite, saltpeter, langbeinite and glauconite) in incubated soil has been discussed.

4.3.1 Water-soluble potassium

Forms of potassium are not bound by soil colloids through cation exchange forces and are present in soil solution as a soluble cation is the water-soluble form of potassium and is susceptible to leaching losses **(Ramamoorthy and Velayutham, 1976)**. When water-soluble K fertilizers are applied, it appreciable amount of potassium is released into the soil solution. An attempt was made to evaluate the amount of potassium released during extraction at the different time periods of 5, 15, 30, 45, 60, and 90 days of incubation (DAI). The data for the release of water-soluble K at 5, 15, 30, 45, 60, and 90 DAIare presented in Table 4.3. The release pattern of successive extraction of water-soluble potassium from K-bearing minerals in incubated soil at 5, 15, 30, 45, 60, and 90 days is given in Figure 4.1. Browsing the data from Table 4.3, it was noticed that a significant variation in the release of potassium from different K-bearing minerals i.e sylvinite, saltpeter, and langbeinite when compared with control and also doubling the doses of sylvinite, saltpeter and langbeinite showed a significant variation on the release of potassium from their respective single-dose treatments. Glauconite did not show significant variation in the release of potassium with control and also no significant difference was observed by doubling its dose except 5 DAI.

Release of K-bearing minerals at 5 DAI, showed no significant difference for T2(P1) and T9(G2), T1 (C) and T8(G1) showed at par result to each other, and also T3 (L1) and T4(L2) showed the non-significant difference. At 15 DAI at par result was observed for T1(C), T8(G1) and T9 (G2) with each other. At 30 DAI there is no significant difference in release found for T1 (C), T8(G1) and T9(G2) with each other and also T2(P1) and T6(S1) showed a non-significant difference with each other. At 45 DAI at par results were found for T1(C), T8(G1) and T9(G2) with each other. At

60 DAI at par result was observed for T1(C), T8(G1) and T9(G2) with each other. In the same way T1(C), T8(G1) and T9(G2) showed at par results with each other.

At the recommended dose of potassium for banana crop (i.e single dose of K-bearing mineral) at 60 DAI the highest release of potassium was observed for T2(P1) i.e 147.24 mg K^+/kg and the lowest was for T8(G1) in respect of control i.e 12.02 mg K^+/kg. T2(P1), T4(L1), T6(S1) showed significantly higher release of K in respect of control T1(control). The order of potassium release from minerals in soil was in the order: T2(P1) > T6(S1) > T4(L1) whereas, G1 showed a non-significant difference with control. But, at 90 DAI (for single dose of K-bearing mineral) highest potassium release was observed for T6(S1) i.e 174.98 mg K^+/kg and lowest was observed f T8(G1) i.e 23.46 mg K^+/kg).Significantly higher release of potassium was observed for T2(P1), T4(L1), T6(S1) in comparison to T1(control) whereas, G1 showed a non-significant difference with control. The order of potassium release from minerals was in the following order: T6(S1) > T2(P1) > T4(L1).

4.3.2 Exchangeable potassium

The exchangeable form of potassium is held to soil colloids by the electrostatic force of attraction like other cations and can be easily replaced or exchanged from the soil with cations of neutral salts solutions on extraction. The amount of K exchanged depends on the type of cation in the soil solution, here neutral solution of 1N ammonium acetate was used for extracting exchangeable K with the ammonium ions (NH_4^+).

An attempt was made to assess the release of exchangeable K^+ by successive extraction of K-bearing minerals in the soil of Inceptisol of Varanasi, at all incubated periods (5, 15, 30, 45, 60, and 90 days). The data for the release at incubated periods from 5 days to 90 days are presented in Table 4.4 and the pattern of release is presented in Figure 4.2. The data from Table 4.4, revealed that T2 (P1), T3(P2), T4(L1), T5(L2), T6(S1), and T7(S2) showed significant variation in the release of K in comparison to T1(C). T8(G1) and T9(G2) released K from glauconite sandstone;

whereas T8(G1) and T9(5.36) were neither significant with each other nor with T1(C).

Application of different K-bearing minerals bought significant difference in the release of exchangeable potassium at all incubation periods. At 5 DAI at par results were observed for T1(C), T8(G1) and T9 (G2) with each other. At 15 DAI non-significant difference was observed between T4(L1) and T6(S1), similarly, a non-significant difference was found among T1(C), T8(G1) and T9 (G2) with each other. At par results were found at 30 DAI for T2(P1) with T6(S1) and between T3(P2) and T5(L2) with each other, similarly, T1(C), T8(G1) and T9 (G2) showed non-significant difference with each other. At 45 DAI, T7 (S2) showed at par result with both T2(P1) and T4(L1) but T2(P1) and T4(L1) showed significant differences from each other and again non-significant difference was found among T1(C), T8(G1) and T9 (G2) with each other. At par result was found between T2(P1) and T4(L1) at 60 DAI, and also T1(C), T8(G1) and T9 (G2) were at par with each other. At 90 DAI, T3(P2) was at par with T7(S2), T4(L1) was at par with T6(S1) and also T1(C), T8(G1) and T9 (G2) are at par with each other.

At the recommended dose of potassium for banana crop (i.e single dose of K-bearing mineral) at 60 DAI the highest release of potassium was observed for T6(S1) i.e 431.86 mg K^+/kg and the lowest was for T8(G1) i.e 95.29 mg K^+/kg. T2(P1), T4(L1), T6(S1) showed significantly higher release of potassium in comparison to T1(control). The order of potassium release was noticed in the order: T6(S1) > T2(P1) and T6(S1) > T4(L1), non-significant variation was observed between T2(P1) and T4(L1) whereas, G1 showed a non-significant difference with control. But, at 90 DAI (for single dose of K-bearing mineral) highest potassium release was observed for T2(P1) i.e 460.10 mg K^+/kg and the lowest was observed for T8(G1) i.e 112.86 mg K^+/kg). Significantly higher amount of release of potassium was observed for T2(P1), T4(L1), T6(S1) in respect of T1(control) and T4(L1) was at par to T6(S1) whereas, G1 showed a non-significant difference with control. The order of potassium release at 90 DAI was in the order of : T6(S1) > T2(P1) and also T6(S1) > T4(L1).

Table 4.4 Release of ammonium acetate extractable potassium (NH_4OAc-K) in soil treated with K-bearing minerals

Treatment	**Doses of K-bearing minerals (g/250g soil)**	**Release of potassium (mg/kg)**					
		Period of incubation (Days)					
		5	**15**	**30**	**45**	**60**	**90**
T1 (C)	**0.00**	86.9±1.78 **g**	106.47±4.18 **f**	94.97±1.84 **e**	94.29±1.17 **f**	97.71±1.68**f**	106.02±4.96 **e**
T2 (P1)	**0.37**	161.77±31.78 **f**	324.59±45.74 **e**	405.53±8.54 **c**	406.76±8.68 **d**	391.84±4.97**e**	460.10±25.3 **c**
T3 (P2)	**0.74**	243.79±24.07 **e**	451.48±21.93 **c**	652.33±15.26 **b**	658.73±18.55 **b**	806.73±12.74**a**	744.44±16.31 **a**
T4 (L1)	**0.76**	272.19±13.76 **d**	369.03±38.96 **d**	351.43±58.04 **d**	359.55±32.84 **e**	384.95±5.16**e**	412.64±14.23 **d**
T5 (L2)	**1.52**	461.73±5.69 **a**	547.18±2.20 **b**	629.25±24.53 **b**	553.59±12.32 **c**	626.24±33.27**c**	710.80±27.21 **b**
T6 (S1)	**0.27**	305.34±3.34 **c**	405.29±15.76 **d**	409.71±8.81 **c**	385.95±4.07 **de**	431.86 ±198.29**d**	393.44±7.40 **d**
T7 (S2)	**0.54**	412.91±8.69 **b**	702.22±13.87 **a**	762.84±19.07 **a**	726.18±30.56 **a**	777.80±19.62**b**	775.10±31.47 **a**
T8 (G1)	**2.78**	83.48±3.39 **g**	96.97±0.69 **f**	92.69±2.79 **e**	94.28±1.96 **f**	95.29±4.31**f**	112.86±10.14 **e**
T9 (G2)	**5.36**	83.77±3.02 **g**	104.55±0.21**f**	93.68±3.53 **e**	89.82±0.98 **f**	90.16±0.45**f**	104.72± 4.04 **e**
Mean		234.6563	345.3133	388.0511	374.3537	410.884	424.459
SEm (±)		8.439	12.990	13.254	9.829	7.803	10.611
CD (P=0.05)		25.072	38.593	39.377	29.201	23.182	31.523

C= Control; P= Saltpeter; L= Langbeinite; S= Sylvinite; G= Glauconite

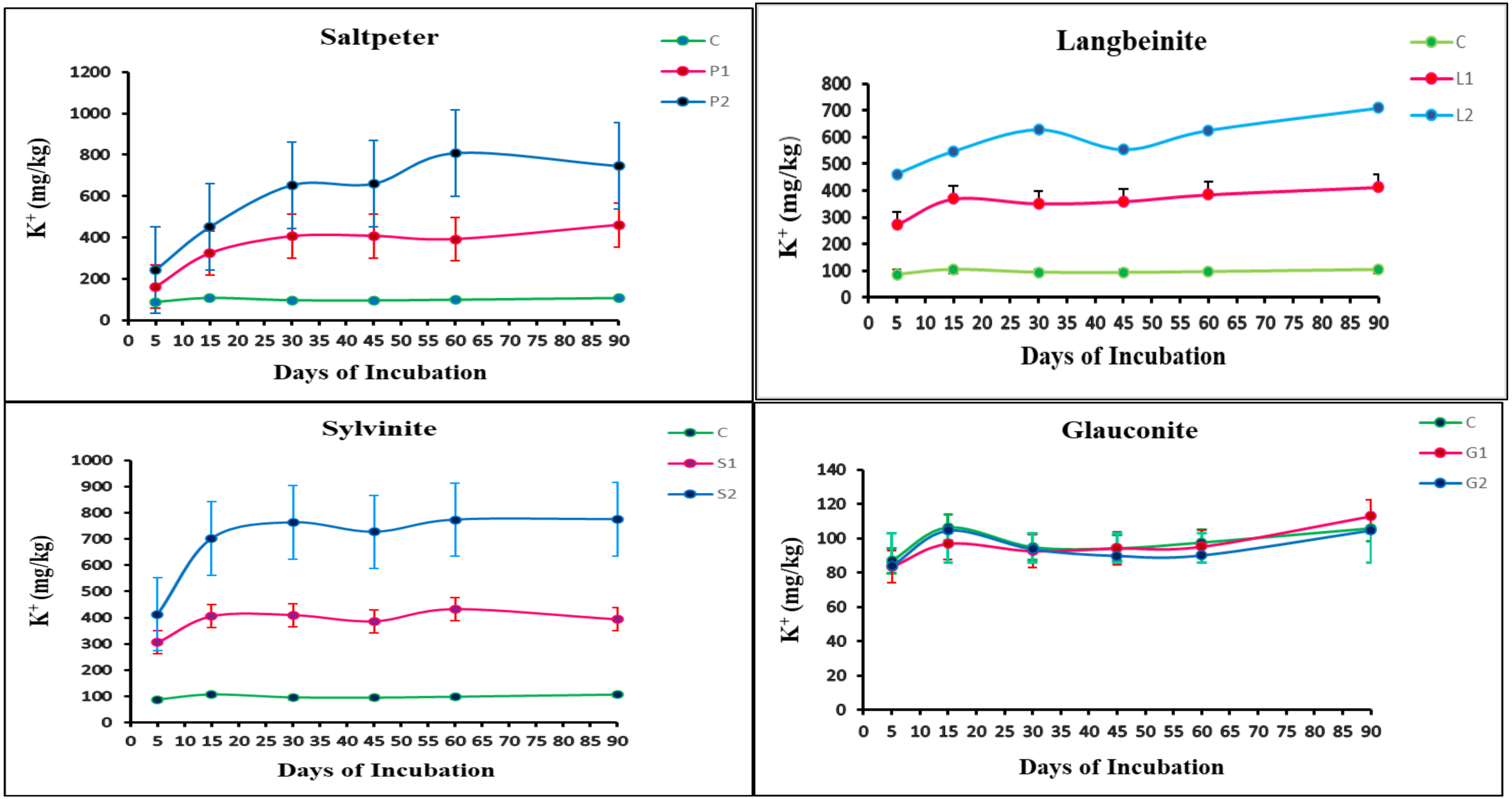


Fig 4.2 Release pattern of plant available K^+ (mg of K^+/kg of soil) in soil treated with K -bearing minerals

(C= Control; P= Salt Peter; L= Langbeinite; S= Sylvinite; G= Glauconite; 1= single dose, 2= double dose)

4.3.3 Non-Exchangeable potassium

Non-exchangeable potassium is held at inter-lattice positions of clay and thus is not easily available to plants, however, it remains in equilibrium with available forms and hence acts as a reservoir of slowly available K **(Perkins, 1973)**. The non-exchangeable form of potassium cannot be extracted by ammonium acetate **(Ramamoorthy and Velayutham, 1976)**.

The attempt was made to find out the release of non-exchangeable potassium by using 1M HNO_3 solution for extraction from K-bearing minerals in the soil for all incubated periods i.e 5, 15, 30, 45, 60 and 90 days. The data for the release of non-exchangeable potassium by successive extraction for 5, 15, 30, 45, 60 and 90 days are given in Table 4.5 and the pattern of release is given in Figure 4.3. Browsing the data from Table 4.5 revealed that the reserved amount of non-exchangeable K from different K-bearing minerals showed a significant difference with the increasing days of incubation (5 to 90 days).

A non-significant difference was observed between T2(P1) and T3(P2) at 5 DAI and also T4(L1), T6(S1) and T9(G2) are at par with each other, T7(S2) showed non-significant variation with T6(S1), T8(G1) and T9(G2). At 15 DAI, the effect of K-bearing mineral's treatment T1(C) showed at par result with T5(L2) and similarly T6(S1), T8(G1) and T9(G2) showed at par result with each other also T4(T5) showed at par result with T6(S1), T7(S2), T8(G1) and T9(G2). Non-significant variation was observed among T2(P1), T5(L2) and T7(S2), similarly T3(P2), T6(S1) and T9(G2) showed at par result to each other. At 45 DAI T1(C) and T9(G2) are at par with each other, T2(P1) and T5(L2) are at par to each other and also both showed at par result to T4(L1), T6(S1) and T7(S2) with each other. At 60 DAI, T1 (C) showed at par result with T2(P1), T4(L1), T5(L2) and T7(S2). Non-significant variation was observed among T2(P1), T3(P2) and T6(S1), at par result was observed for T4(L1) and T5(L2) with each other, similarly, T1(C), T7(S2) and T8(G1) showed at par results.

At the recommended dose of potassium for the banana crop (i.e the single-dose application of K-bearing mineral) at 60 DAI, the highest reserved potassium was observed for T6(S1) i.e 1263.00 mg K^+/kg and the lowest was for T8(G1) i.e 1026.00 mg K^+/kg. T4(L1), T6(S1) showed significantly higher amount of potassium reserved with respect of T1(control) whereas T8(G1) showed significantly low amount of potassium rserved than T1(Control). The order of potassium reserved was in the order: T6(S1) > T2(P1) > T4(L1) > T8(G1) and non-significant variation was observed between T2(P1) and T1(Control). But, at 90 DAI (for single-dose application of K-bearing mineral) highest amount of K reserved was observed for T6(S1) i.e 1412.00 mg K^+/kg and the lowest was observed for T8(G1) i.e 1176.00 mg K^+/kg). Significantly higher amount of reserved potassium was observed for T2(P1), T4(L1), T6(S1) and T8(G1) with respect to T1(control) and T2(P1) was at par to T6(S1) whereas, (T8)G1 showed a non-significant difference with control. The order of potassium reserved from minerals amended in soil was in the order: T6(S1) > T4(L1) > T8(G1).

4.4 Cumulative K release

An attempt was made to find out the pattern of cumulative release of non-exchangeable K from K-bearing minerals in incubated soils for all periods of incubation (5, 15, 30, 45, 60, and 90 days). The findings are presented in Figure 4.4 and data is presented in Table 4.6. Browsing through data from Table 4.6 it was analysed that in comparison to control i.e 0.00g K-bearing mineral per 250 g soil (T_1) amount of cumulative release (mg/kg) for T_3(P1) was maximum (270.80 mg kg^{-1}) at 5 DAI or 120 hours and at 15 DAI or 360 hours T5(L2) showed maximum cumulative release of 367.46 mg kg^{-1}. The highest cumulative release of non-exchangeable K was recorded at 90 DAI or 2160 hours in soil treated with 1.52g of langbeinite per 250 g soil (T5) increased by 433.02 mg K^+/ kg over its initial days of incubation (5 DAI or 120 hours) i.e 242.80 mg K^+/ kg.

The application of different K-bearing minerals brought significant variation in cumulative K release at all periods of incubation. At 5 DAI (120 hours) T1 (C), T8(G1) and T9(G2) showed at par result with each other, T2(P1) and T4(L1) showed at par result and T7(S2) showed at par result with both T3(P2) and T5(L2). At 15 DAI (360 hours) control i.e 0.00 g of K-bearing mineral (T1) showed significant variation with every treatment except with T8(G2) and T9(G2) it showed non-significant variation and likewise 0.54 g of sylvinite for 250 g soil (T7) showed at par result with T3 and T5 both. At 30 DAI (720 hours) at par result was observed for T1(C), T8(G1) and T9(G2) with each other whereas other treatments T2, T3, T4, T5, T6, and T7 noticed significant variation with T1. At 45 DAI (1080 hours) highest cumulative release was observed for 1.52g of langbeinite for 250 g of soil (T5) and all T1(C), T8(G1) and T9(G2) observed at par result with each other. Similarly, T2(P1), T4(L1) and T6(S1) together showed non-significant variation. The highest active release at 60 DAI (1440 hours) was observed for T5 i.e 474.94 mg K^+/kg and at par result was obtained for T1(C), T8(G1) and T9(G2) with each other, and T4(L1) was non-significantly different from T6(S1). At 90 DAI (2160 hours) T3(P2) was at par with T7(S2) and T4 (L1) was at par with T6(S1) and also T1(C), T8(G1) and T9(G2) also showed at par result with each other.

At the recommended dose of potassium for the banana crop (i.e the single-dose application of K-bearing mineral) at 60 DAI, the highest release of potassium was observed for T6(S1) i.e 203.88 mg K^+/kg and the lowest was for T8(G1) i.e 39.43 mg K^+/kg. T4(L1), T6(S1) showed significantly higher potassium release in comparison to control (T1) whereas T8(G1) showed non-significant variation with T1(Control). The order of potassium release in soil amended with K-bearing minerals was in the order: T6(S1) > T2(P1) > T8(G1) and non-significant variation was observed between T4(L1) and T6(S1). But, at 90 DAI (for single-dose application of K-bearing mineral) highest potassium release was observed for T4(L1) i.e 213.58 mg K^+/kg and the lowest was observed for T8(G1) i.e 47.62 mg K^+/kg). Significantly high release of potassium was observed for T2(P1), T4(L1), T6(S1) and T8(G1) in respect to T1(control), moreover T4(L1) was at par to T6(S1) whereas, (T8)G1 showed a non-significant difference with control. The order of potassium release was in the order: T4(L1) > T2(P1) > T8(G1).

Table 4.5 Non-exchangeable potassium (HNO_3-K) in soil treated with K- bearing minerals

Treatment	**Doses of K- bearing minerals (g/250g soil)**	**Non- exchangeable potassium (mg/kg)**					
		Period of incubation (Days)					
		5	**15**	**30**	**45**	**60**	**90**
T1 (C)	**0.00**	1010.33±13.01**f**	1065.00±48.86**e**	1061.00±21.37**d**	1141.00±2.64**e**	1063.33±12.66**de**	1168.00±28.47**c**
T2 (P1)	**0.37**	1303.66±36.69**a**	1480.00±14.00**b**	1244.33±12.66**a**	1261.33±68.31**bc**	1089.33±4.041**d**	1374.00±10.14**a**
T3 (P2)	**0.74**	1279.66±27.15**a**	1633.33±35.30**a**	1164.66±20.74**b**	1353.33±14.64**a**	1306.66±24.17**a**	1368.33±52.62**a**
T4 (L1)	**0.76**	1056.00±14.17**e**	1271.66±83.36**cd**	1119.66±18.92**c**	1218.33±15.53**cd**	1038.33±24.68**ef**	1256..33±646.94**b**
T5 (L2)	**1.52**	1196.66±9.29**b**	1100.33±28.53**e**	1248.33±43.31**a**	1262.00±18.52**bc**	1035.33±6.02**ef**	1252.66±35.92**b**
T6 (S1)	**0.27**	1073.66±7.02**de**	1226.33±20.40**d**	1177.33±21.73**b**	1291.66±18.52**b**	1263.00±27.62**b**	1412.00±7.93**a**
T7 (S2)	**0.54**	1103.66±21.22**cd**	1325.66±42.82**c**	1256.00±10.44**a**	1215.66±17.47**cd**	1076.66±12.05**d**	1154.66±22.50**c**
T8 (G1)	**2.76**	1135.66±33.08**c**	1240.66±29.14**d**	967.66±37.07**e**	1188.00±11.53**d**	1026.00±13.11**g**	1176.00±16.64**c**
T9 (G2)	**5.36**	1084.66±9.86**de**	1244.33±9.50**d**	1191.00±4.58**b**	1115.00±3.00**e**	1195.66±14.64**c**	1046.66±6.35**d**
Mean		1138.222	1287.481	1158.889	1227.370	1121.593	1202.926
SEm (±)		12.521	23.403	13.958	15.223	10.003	125.392
CD (P=0.05)		37.197	69.528	41.467	45.226	29.7199	372.516

C= Control; P= Saltpeter; L= Langbeinite; S= Sylvinite; G= Glauconite

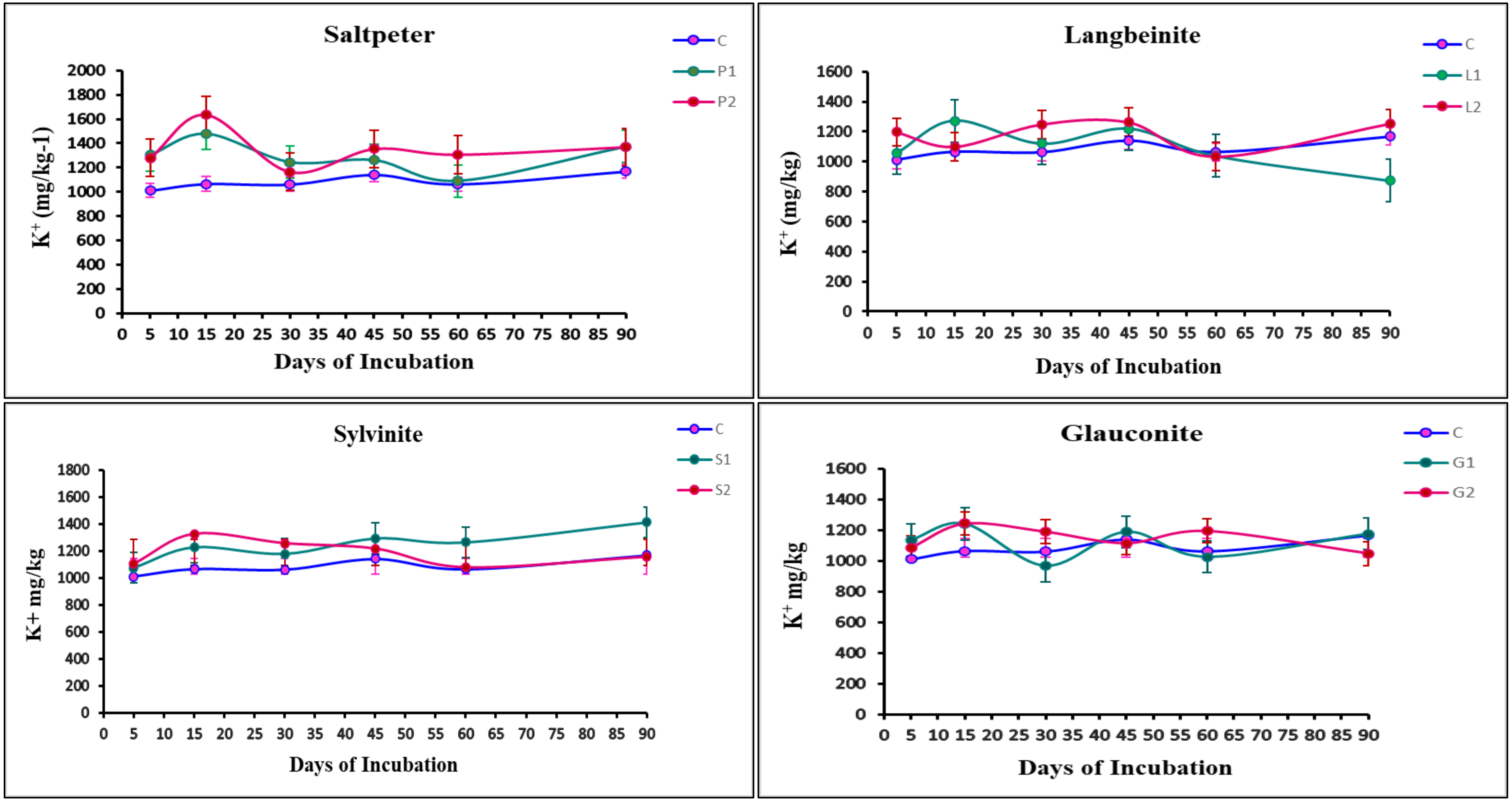


Fig 4.3 Release pattern of non-exchangeable K$^+$ (mg of K$^+$/kg of soil) in soil treated with K -bearing minerals

(C= Control; P= Salt Peter; L= Langbeinite; S= Sylvinite; G= Glauconite; 1= single dose, 2= double dose)

4.5 Release kinetics of potassium in soil

An effort was made to find out the kinetics of K release from K-bearing minerals in the soil for all the periods of incubation (5, 15, 30, 45, 60 and 90 days). The data for successive extraction of soil for potassium release kinetics are presented in Table 4.7. After browsing the data from Table 4.7 the decline in release kinetics was observed i.e at 5 DAI highest release kinetics was observed and the lowest was observed at 90 DAI. The comparative decline in values was observed for successive periods of incubation in order: 5 DAI > 15 DAI > 30 DAI > 45 DAI > 60 DAI > 90 DAI. The highest value for release kinetics was for T3(P2) at 5 DAI, but T5 (L2) showed continuously highest release kinetics from 15 DAI (1.020 mg K^+/kg) to 90 DAI (0.200 mg K^+/kg) in comparison to other treatments of K-bearing minerals. The significant variation was observed for K- bearing minerals with control (T1) except treatment T8(G1) and T9(G2) which showed non-significant variation with the control (T1) from 5 DAI till 90 DAI. At 5 DAI at par result was observed for T2(P1) and T4(L1) with each other, T7(S2) was at par with both T3(P2) and T5(L2). At 15 DAI T7(S2) was at par with both T2(P1) and T4(L1) similarly, at par result was observed for T4(L1) with T6(S1). Non-significant difference at 30 DAI was found for T2(P1), T4(L1) and T6(S1) with each other; but all these three treatments showed significant variation with T3(P2), T5(L2) and T7(S2). At 60 DAI non-significant variation was observed between T4(L1) and T6(S1) with each other. At 90 DAI at par result was between T3(P2) and T7(S2) with each other, similarly, T4(L1) was at par with T6(S1).

At the recommended dose of potassium for the banana crop (i.e the single-dose application of K-bearing mineral) at 60 DAI, the highest release kinetics of potassium was observed for T6(S1) i.e 0.141 mg K^+/kg soil/ h and the lowest was for T8(G1) i.e 39.43 mg K^+/kg soil/h. T2(P1), T4(L1), and T6(S1) showed significantly higher potassium release kinetics in soil with T1(control) whereas T8(G1) showed non-significant variation with T1(Control). The order of potassium release in soil was in the order: T6(S1) > T2(P1) > T8(G1) and non-significant variation was observed between T4(L1) and T6(S1). But, at 90 DAI (for single-dose application of K-bearing mineral) highest potassium release was observed for T4(L1) i.e 0.098 mg K^+/kg soil/h and the lowest was observed for T8(G1) i.e 0.022 mg K^+/kg soil/h. Significantly higher amount of release of potassium was observed for T2(P1), T4(L1), and T6(S1) with respect to T1(control); moreover T4(L1) was at par with T6(S1). Further, (T8) G1 showed a non-significant difference with control. The order of potassium release kinetics in soil at 90 DAI was in the order: T4(L1) > T2(P1) > T8(G1).

Table 4.6 Cumulative amount of K* released with time in soil treated with K-bearing minerals

Treatment	**Doses of K- bearing minerals (g/250g soil)**	**Release of potassium (mg/kg)**					
		Period of incubation (Days)					
		5	**15**	**30**	**45**	**60**	**90**
T1 (C)	**0.00**	50.14±0.19**e**	55.60±1.67**f**	61.96±1.13**e**	36.31±1.77**e**	36.87±4.05**f**	47.12±0.44**e**
T2 (P1)	**0.37**	118.05±10.85 **d**	225.15±51.43**c**	233.81±15.84**d**	130.96±35.62**d**	117.94±10.67**e**	128.53±17.00**d**
T3 (P2)	**0.74**	270.80±14.85**a**	275.98±26.28**b**	491.32±34.02**b**	228.39±23.96**c**	295.66±20.14**c**	293.13±56.63 **b**
T4 (L1)	**0.76**	111.51±8.36**d**	140.36±5.72**e**	237.56±13.72**d**	159.04±10.53**d**	201.42±2.76**d**	213.58±12.83**c**
T5 (L2)	**1.52**	242.16±36.26**b**	367.46±53.37**a**	581.95±32.99**a**	369.32±30.65**a**	474.94±10.98**a**	433.02±13.49**a**
T6 (S1)	**0.27**	186.01±10.14**c**	114.64±7.20**e**	235.90±17.96**d**	153.25±6.29**d**	203.88±13.22**d**	199.69±50.15**c**
T7 (S2)	**0.54**	249.27±20.43**ab**	179.43±32.27**cd**	457.24±9.93**c**	278.24±16.89**b**	351.75±21.41**b**	295.70±20.16**b**
T8 (G1)	**2.78**	49.90±0.22**e**	58.246670.32**f**	64.82±1.78**e**	37.31±2.17**e**	39.43±4.28**f**	47.62±0.26**e**
T9 (G2)	**5.36**	28.63±4.39**e**	56.5±1.94**f**	63.87±0.22**e**	35.32±1.13**e**	35.31±1.39**f**	54.03±0.93**e**
Mean		145.166	163.709	269.828	158.685	195.247	190.271
SEm (±)		9.157	16.465	10.737	10.935	6.988	15.833
CD (P=0.05)		27.205	48.915	31.898	32.488	20.760	47.038

C= Control; P= Saltpeter; L= Langbeinite; S= Sylvinite; G= Glauconite ***($CaCl_2$ extractable K- soil solution K)**

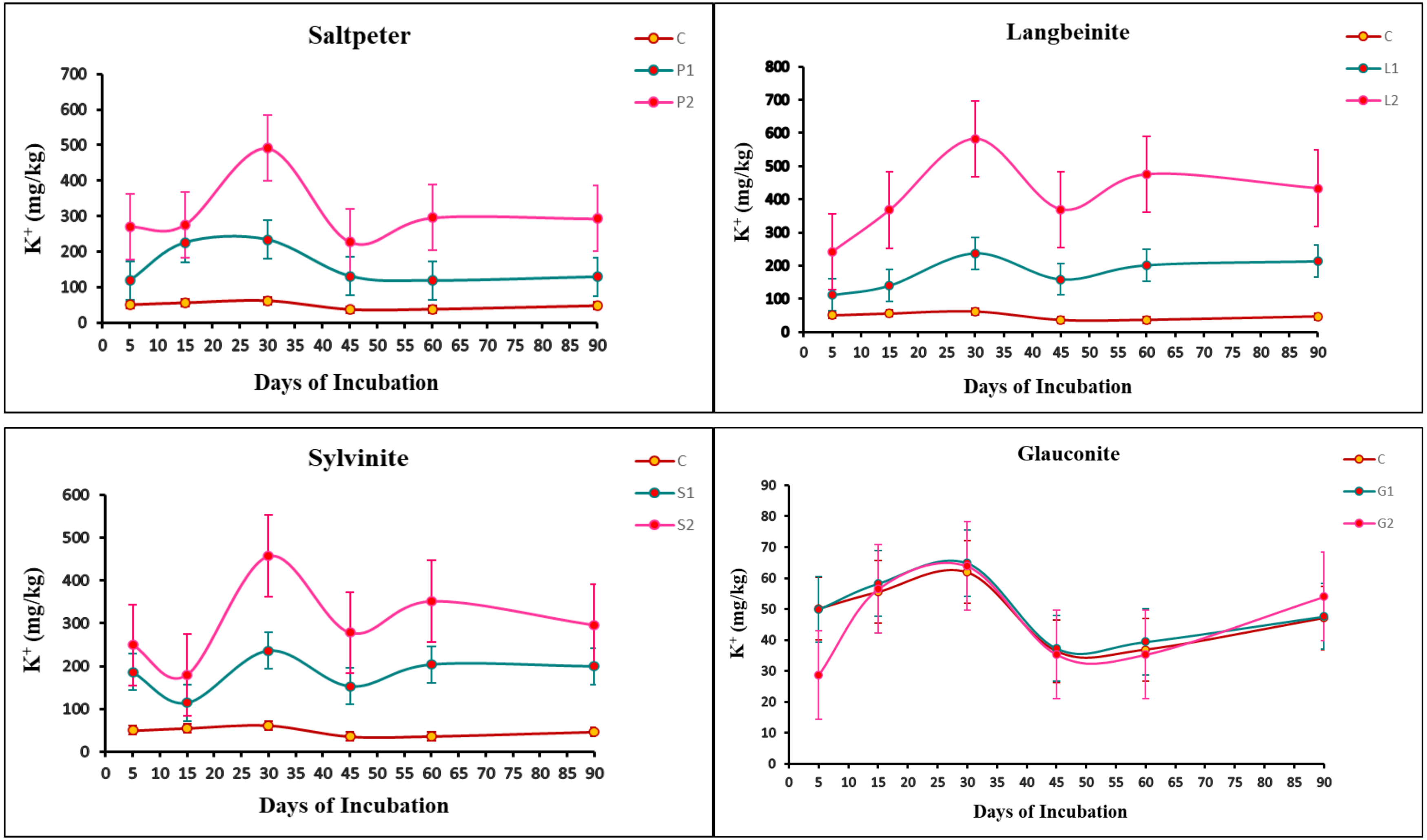


Fig. 4.4 Cumulative amount of K released (mg/kg) with days in soils treated with K-bearing minerals

Table 4.7 Potassium release kinetics in soil treated with K-bearing minerals

(C= Control; P= Salt Peter; L= Langbeinite; S= Sylvinite; G= Glauconite; 1= single dose, 2= double dose) **Treatment**	**Doses of K- bearing minerals (g/250g soil)**	**Potassium release kinetics (mg K^+/kg soil/h)**					
		Period of incubation (Days)					
		5	**15**	**30**	**45**	**60**	**90**
T1 (C)	**0.00**	0.417±0.0015**e**	0.154±0.0046**f**	0.086±0.0015**e**	0.033±0.0016**e**	0.025±0.0028**f**	0.021±0.0002**e**
T2 (P1)	**0.37**	0.983±0.0904**d**	0.625±0.1428**c**	0.324±0.1250**d**	0.121±0.0329**d**	0.081±0.0074**e**	0.059±0.0078**d**
T3 (P2)	**0.74**	2.256±0.1237**a**	0.766±0.0730**b**	0.682±0.0472**b**	0.211±0.0221**c**	0.205±0.0139**c**	0.135±0.0262**b**
T4 (L1)	**0.76**	0.929±0.0697**d**	0.389±0.0159**de**	0.329±0.0190**d**	0.147±0.0097**d**	0.139±0.0019**d**	0.098±0.0059**c**
T5 (L2)	**1.52**	2.018±0.3022**b**	1.020±0.1482**a**	0.808±0.0458**a**	0.341±0.0283**a**	0.329±0.0076**a**	0.200±0.0062**a**
T6 (S1)	**0.27**	1.550±0.0845**c**	0.318±0.0200**e**	0.327±0.0249**d**	0.141±0.0058**d**	0.141±0.0091**d**	0.092±0.023**c**
T7 (S2)	**0.54**	2.077±0.1703**ab**	0.498±0.0896**cd**	0.635±0.0138**c**	0.257±0.0156**b**	0.244±0.0148**b**	0.136±0.0093**b**
T8 (G1)	**2.78**	0.415±0.001**e**	0.161±0.0008**f**	0.090±0.0024**e**	0.034±0.0020**e**	0.027±0.0029**f**	0.022±0.0001**e**
T9 (G2)	**5.36**	0.238±0.036**e**	0.156±0.0053**f**	0.088±0.0003**e**	0.032±0.0010**e**	0.024±0.0004**f**	0.025±0.0004**e**
Mean		1.209	0.454	0.374	0.146	0.135	0.088
SEm (±)		0.076	0.045	0.014	0.010	0.004	0.007
CD (P=0.05)		0.226	0.135	0.044	0.030	0.014	0.021

C= Control; P= SaltPeter; L= Langbeinite; S= Sylvinite; G= Glauconite

4.6 IMPACT OF SOIL AMENDED POTASSIUM BEARING MINERALS ON ELECTROCHEMICAL PROPERTIES OF SOIL

4.6.1 Soil pH

The effort was made to find that the K-bearing minerals change the pH of the soil at different time periods of incubation. The recorded data are presented in Table 4.8 and the graph of the same data is presented in Figure 4.5 showing pH in relation to days of incubation (5, 15, 30, 45, 60, and 90 days). From the bar graph given in Figure 4.5, it was observed that the highest pH was found for T8(G1) and T9(G2) from 5 DAI to 90 DAI in comparison to control (T1). From Table 4.8 significant variation in pH was found between K-bearing minerals and control (T1), the highest pH of 7.86 was observed for T9(G2) and the lowest pH of 6.96 was observed for T5(L2) at 90 DAI.

Application of T4(L1) in soil showed non-significant variation with both T5(L2) and T7(S2) at 5 DAI. At 15 DAI treatments T2(P1), T6(S1) and T7(S2) are at par with T3(P2), T4(L1), and T5(L2). Treatments T2(P1) and T7(S2) both showed non-significant variation with T3(P2), T4(L1), and T6(S1) at 30 DAI. At 45 DAI non-significant variation was found between T8(G1) and T9(G2) and T6(S1) was at par with both T2(P1) and T4(L1), similarly, T3(P2) was at par with both T5(S1) and T7(S2). At 60 DAI treatments T8(G1) and T9(G2) are at par with each other and T4(L1) was at par with all T2(P1), T3(P2), T5(L2) and T7(S2). At 90 DAI significant variation was observed between T8(G1) and T9(G2), and T2(P1) and T4(L1) were non-significant with both T3(P2) and T7(S2).

4.6.2 EC of soil

An attempt was also made to evaluate the effect of K-bearing minerals on EC of soil for all periods of incubation (5, 15, 30, 45, 60 and 90 days) and data for EC of soils are presented in Table 4.9 and graph for the same data is presented in Figure 4.6. Analysis of data revealed a significant variation of K-bearing minerals (T2, T3, T4, T5, T6, and T7) with control(T1) except for T8(G1) and T9(G2). From Figure 4.6, it could be observed that from 5 DAI till 90 DAI highest EC was observed for T5 i.e 1.52 g of langbeinite in soil and at par result for T8(G1) and T9(G2) both found with T1 from 5 DAI till 90 DAI due to accumulation of sulphate (SO_4^{2-}) and magnesium (Mg^{2+}) in soil solution.

Table 4.8 Periodical changes of pH in soil treated with K-bearing minerals

Treatment	**Doses of K-bearing minerals (g/250g soil)**	**Soil pH_w (1:2.5)**					
		Period of Incubation (Days)					
		5	**15**	**30**	**45**	**60**	**90**
T1 (C)	**0.00**	7.49±0.037**c**	7.41±0.049**b**	7.43±0.032**b**	7.43±0.005**b**	7.49±0.055**b**	7.43±0.055**c**
T2 (P1)	**0.37**	7.13±0.010**e**	7.17±0.066**c**	7.25±0.010**c**	7.16±0.010**cd**	7.20±0.005**d**	7.05±0.041**f**
T3 (P2)	**0.74**	7.08±0.036**f**	7.07±0.015**cd**	7.20±0.097**cd**	7.01±0.005**e**	7.04±0.005**e**	7.07±0.010**ef**
T4 (L1)	**0.76**	7.04±0.011**g**	7.09±0.030**cd**	7.17±0.106**cd**	7.196±0.219**cd**	7.14±0.010**de**	7.12±0.035**e**
T5 (L2)	**1.52**	7.06±0.010f**g**	7.04±0.015**cd**	6.843±0.126**e**	7.00±0.036**e**	7.05±0.010**e**	6.96±0.045**g**
T6 (S1)	**0.27**	7.20±0.005**d**	7.18±0.010**c**	7.17±0.010**cd**	7.28±0.020**c**	7.36±0.020**c**	7.21±0.015**d**
T7 (S2)	**0.54**	7.03±0.005**g**	7.01±0.195**d**	7.11±0.010**d**	7.13±0.041**de**	7.20±0.010**d**	7.10±0.010**ef**
T8 (G1)	**2.78**	7.71±0.020**b**	7.62±0.020**a**	7.716±0.015**a**	7.75±0.020**a**	7.80±0.020**a**	7.71±0.041**b**
T9 (G2)	**5.36**	7.80±0.005**a**	7.68±0.025**a**	7.52±0.020**b**	7.80±0.046**a**	7.73±0.158**a**	7.86±0.045**a**
MEAN		7.285	7.255	5.131	5.158	5.163	5.127
Sem (±)		0.011	0.041	0.037	0.044	0.033	0.021
CD (P= 0.05)		0.034	0.124	0.112	0.133	0.098	0.063

C= Control; P= Saltpeter; L= Langbeinite; S= Sylvinite; G= Glauconite

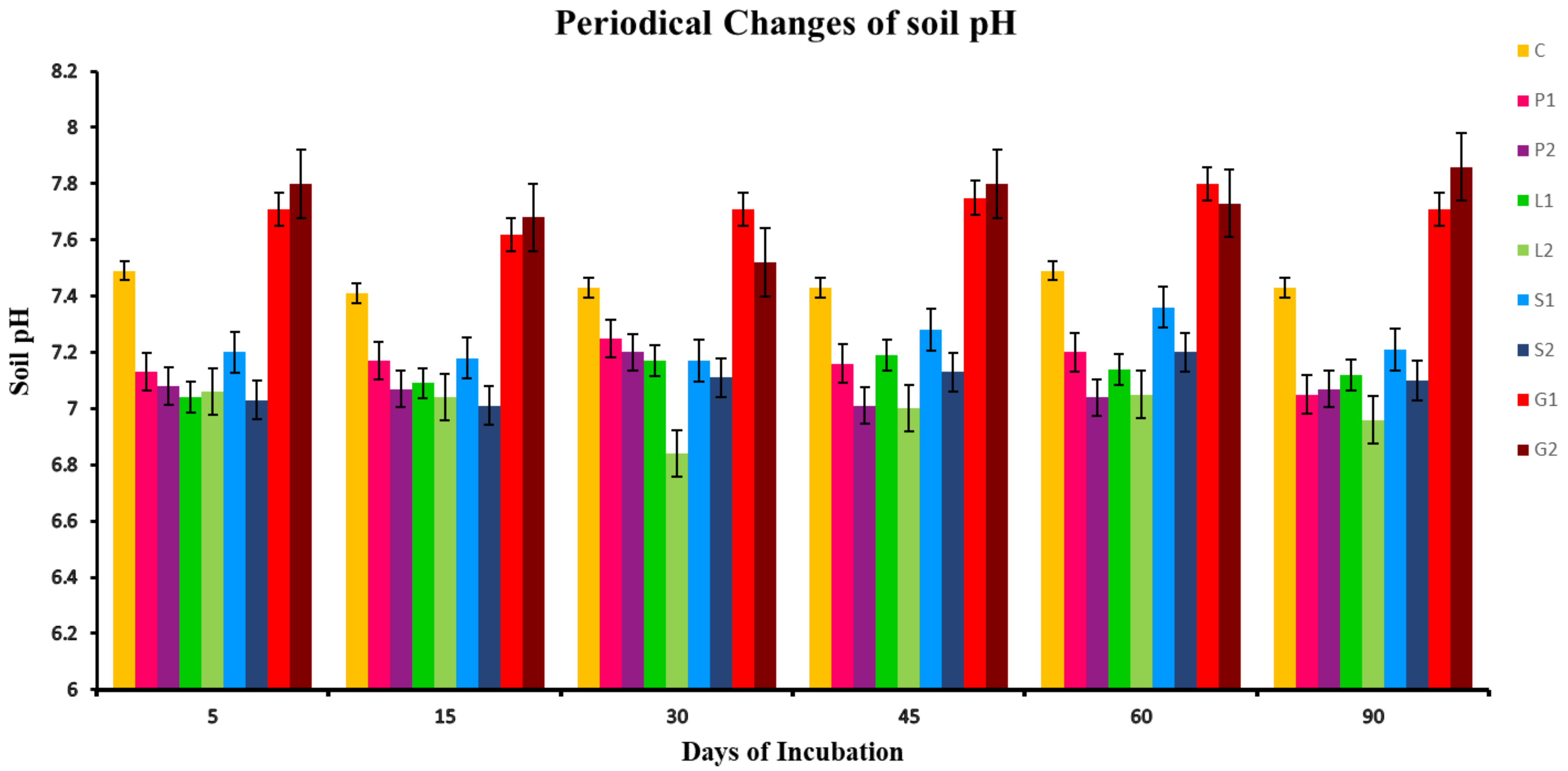


Fig. 4.5 Periodical changes of pH in soil treated K- bearing minerals

(C= Control; P= Salt Peter; L= Langbeinite; S= Sylvinite; G= Glauconite; 1= single dose, 2= double dose)

Table 4.9 Periodical changes of electrical conductivity (EC) in soil treated with K-bearing minerals

Treatment	**Doses of K-bearing minerals (g/250g soil)**	**EC of the soil (dSm^{-1})**					
		Period of Mineralization (Days)					
		5	**15**	**30**	**45**	**60**	**90**
T1 (C)	**0.00**	0.294±0.008**f**	0.297±0.010**e**	0.353±0.003**d**	0.383±0.010**d**	0.339±0.002**e**	0.410±0.010**f**
T2 (P1)	**0.37**	0.810±0.052**e**	0.835±0.088**d**	0.756±0.032**cd**	0.835±0.021**c**	1.010±0.041**cd**	1.090±0.019**d**
T3 (P2)	**0.74**	1.621±0.029**c**	1.447±0.100**c**	1.422±0.113**b**	1.338±0.064**b**	1.362±0.651**bc**	1.429±0.031**c**
T4 (L1)	**0.76**	1.762±0.027**b**	1.728±0.071**b**	1.156±0.672**bc**	1.130±0.693**bc**	1.463±0.033**b**	1.368±0.111**c**
T5 (L2)	**1.52**	2.607±0.063**a**	2.780±0.002**a**	2.561±0.027**a**	2.497±0.065**a**	2.533±0.138**a**	2.373±0.067**a**
T6 (S1)	**0.27**	0.886±0.008**d**	0.896±0.032**d**	0.891±0.035**c**	0.854±0.050**c**	0.851±0.167**d**	0.857±0.068**e**
T7 (S2)	**0.54**	1.662±0.015**c**	1.642±0.033**b**	1.512±0.010**b**	1.509±0.010**b**	1.391±0.207**bc**	1.702±0.004**b**
T8 (G1)	**2.78**	0.318±0.001**f**	0.330±0.001**e**	0.392±0.004**d**	0.386±0.007**d**	0.414±0.002**e**	0.428±0.0023**f**
T9 (G2)	**5.36**	0.318±0.001**f**	0.339±0.007**e**	0.381±0.036**d**	0.368±0.015**d**	0.391±0.005**e**	0.437±0.004**f**
MEAN		1.142	1.144	1.047	1.033	1.084	1.121
SEm (±)		0.017	0.030	0.131	0.135	0.138	0.029
CD (P=0.05)		0.053	0.091	0.391	0.401	0.411	0.086

C= Control; P= Saltpeter; L= Langbeinite; S= Sylvinite; G= Glauconite

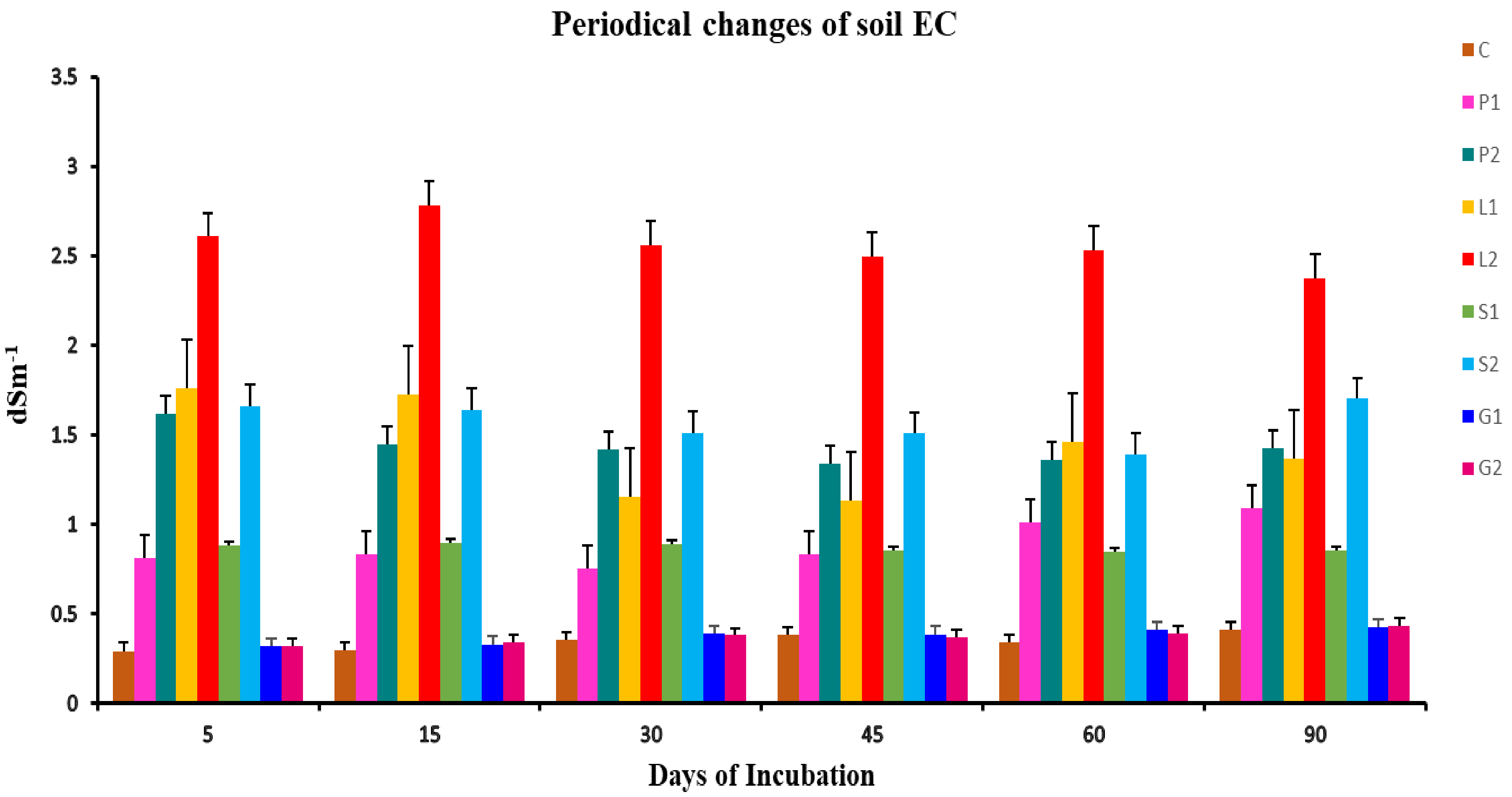


Fig. 4.6 Periodical changes of EC of soil treated K- bearing minerals
(C= Control; P= Salt Peter; L= Langbeinite; S= Sylvinite; G= Glauconite; 1= single dose, 2= double dose)

At 5 DAI, T3(P2) was at par with T7(S2). At par result was obtained for T2(P1) with T6(S1) and for T4(L1) with T7(S2) at 15 DAI. At 30 DAI only T5(L2) showed at par result with every treatment. At 45 DAI both T2(P1) and T3(P2) are at par with T4(L1), T6(S1) and T7(S2). Non-significant variation was found between T2(P1) and T6(S1), similarly, T3(P2) was at par with T4(L1), and T7(S2) at 60 DAI.

4.7 SALT INDEX VALUES OF POTASSIC FERTILIZER MATERIAL

The salt index was developed by Rader *et al*., (1943). A fertilizer's salt index measures how much fertilizer increases the osmotic pressure of a soil solution with a given amount and is compared to same weight of sodium nitrate ($NaNO_3$), where $NaNO_3$ is assigned to a relative value of 100 as sodium nitrate is 100% soluble in water. Although salt indexes cannot identify the exact amount of a fertilizer material or formulation that might cause crop injury on a particular soil, they do allow comparisons of fluid formulations for their potential salt effect on a given soil.

The main purpose of salt index is that fertilizers can be classified on the basis of their injury levels. The fertilizers having high salt index are injurious to seed and plant growth than fertilizer with low salt index. Different crops have different tolerance level to salt concentration. The salt index helps in formulating fertilizer and selection of fertilizers which will be used in proximity to the seed, or the method of applying fertilizers can be decided (broadcasting, band application, furrow application, etc.) hence this will prevent the seedling from injury.

An effort has been made to show the list of salt indexes of potassic fertilizer materials in Table 4.10. A high salt index indicates high EC as per the soil conditions and soil type. In Table 4.10 it can be observed that the highest salt index is for potassium chloride i.e 116.2 and langbeinite has a low salt index i.e 43.4 than potassium chloride (sylvite) means ECs from langbeinite solutions are less than those of similar concentrations in KCl solutions. From this laboratory soil incubation experiment it was observed in Table 4.9 that, T5 (L2) i.e langbeinite showed the highest EC from 5 DAI to 90 DAI as compared to T1(control) and T7(S2) i.e sylvite.

Table 4.10 Salt index values of potassic fertilizer materials

S.No.	Name of the fertilizer	%K_2O	Salt index	Partial salt index* Of K-fertilizers
1.	Potassium chloride (MOP), (Sylvite)	60	116.2	1.936
2.	Potassium nitrate (Saltpeter)	44	69.5	1.219
3.	Potassium sulphate (Sulphate of potash:SOP)	50	42.6	0.852
4.	Sulphate of potash-magnesia (Langbeinite)	22	43.4	1.971
5.	Monopotassium phosphate	34.6	8.4	0.097
6.	Potassium thiosulphate	25.0	68.0	2.720
Sodium nitrate ($NaNO_3$)		15.5% N	100	

Source : Mortvedt, 2001.

$$Salt\ Index(SI)of\ fertilizer = \frac{Osmotic\ Pressure_{Fertilizer\ Material}}{Osmotic\ Pressure_{NaNO_3}} \times 100$$

* The salt index of a mixed fertilizer containing N, P, & K is the sum of the salt index valuesPartial Salt Index) of its components

Mortvedt, J.J. (2001) : Calculating salt index, Spring, Pg. 1-3

The salt index in potassium chloride is due to release of chlorine which is highly toxic to plants, in case of langbeinite the high EC is produced due to presence of sulphate ions (SO_4^{2-}) and magnesium (Mg^{2+}) which does not cause injury to plants as that of chloride ions (Cl^-). Thus, considering both the source and release pattern of K in soil, the mineral langbeinite was observed best for K fertilization. Moreover, with the release of K^+ in soil from langbeinite mineral, additional other two most important plant essential nutrient elements, i.e. SO_4^{2-} and Mg^{2+} are released during the release of K^+ in soil and there is no question of salt injury to plants.

* * *

Chapter V

SUMMARY AND CONCLUSION

In this chapter, based on the significance of the findings of the present study entitled **“Potassium release in soil amended with potassium bearing minerals”**, an effort has been made to summarize the experiment and also draw valid conclusions. The investigation was conducted in the year 2021-22 at the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi to study the release pattern of potassium from K-bearing minerals in the soil, through the addition of different K-bearing minerals (salt Peter, sylvinite, langbeinite and glauconite). In addition to the release pattern of potassium, the effect of on the amendment of K-bearing minerals on pH and EC of soil were also studied.

Potassium is considered to be the most important element required for plant and animal life as it is involved in many biochemical processes in plants (**Zorb *et al*., 2014**). The demand for potassium differs from plant to plant and the demand for potassium changes with the growth and developmental stages of the plant **(Kant *et al*., 2005).** Potassium in the soil exists in various forms *viz*. water-soluble K^+, exchangeable K^+, non-exchangeable K^+ (fixed), and mineral potassium (structural K^+) and these forms exist in equilibrium with each other. The easily available potassium for plant uptake is water-soluble K^+ and exchangeable K^+. The non-exchangeable form gets converted to exchangeable form and exchangeable to water-soluble form to maintain the dynamic equilibrium.

In the Indian agricultural system main focus was given to nitrogen and phosphorus as fertilizers by farmers as these fertilizers provide visible results just after their application and the application of potassium was not given much focus. The potassium requirement was fulfilled from soil reserved potassium which has led to K-mining and disturbing the nutrient balance in the soil and affecting soil fertility. Based on recent research conducted across the Indo-Gangetic plains (IGP), without application of potassium fertilizer reduced average rice, wheat, and maize grain yields by 621, 723, and 699 kg ha^{-1} **(Majumdar *et al*., 2012)**. In a growing number of cases, farmers are using K fertilizers to increase the quality, shape, and colour of produce at maturity **(Kinekar, 2010)** due to the visible benefits they obtain from its application. The government of India has also helped in increasing the use of K fertilizers by providing subsidies on the maximum retail price of K fertilizers.

Mineral salts with high elemental concentrations currently meet the K demand **(Fixen and Johnston, 2011)**. A limiting factor in agriculture is soil K availability, so K fertilizers are widely used throughout the world **(Barre *et al*., 2008).** The use of K fertilizers has been important to Indian agriculture in attaining and sustaining food grain self-sufficiency. The demand for fertilizers is increasing year to year and the source is limited. There are only a few countries in the northern hemisphere (Canada, Russia, Belarus, and Germany) that are best suited to the production of K fertilizer commercially. Since India does not have any marine evaporite deposits for potash hence all of India's K fertilizer consumption is imported from foreign countries; it is totally dependent on foreign countries. A huge amount of money is invested in importing potash fertilizers into India. It becomes very important for India to look for indigenous sources of potassium for the production of potash fertilizers for meeting the country’s demand.

India has the deposition of glauconite sandstone/shales majorly at Kota, Karauli, Chittorgarh, Jaisalmer, and Barmer districts of Rajasthan and also some deposition in the Son Valley region covering parts of Madhya Pradesh and Uttar Pradesh. Glauconitic sandstone has the capacity to release plant-necessary potassium and can be a natural potassium fertiliser for sustainable agriculture. The percent of K_2O in glauconite sandstone is 4-8% and although it is a slow-releasing potassium mineral, with the help of technologies it can be exploited commercially and can be used as an indigenous source of fertilizer in India. The glauconite can be directly applied to acid soils or in normal soil can be applied either by treating with organic acids or in the presence of microorganisms releasing organic acids or glauconite nano-particles dissolution with the help of organic acids **(Praveen and Tomar, 2019; Rakesh *et al*., 2020).**

To evaluate the release pattern of potassium through potassium-bearing minerals, surface soil (50 kg) was collected from the cultivated field of Agricultural Research Farm of Banaras Hindu University, Varanasi district in Uttar Pradesh. Langbeinite was collected from The Mosaic Company, Mosaic India, Tower 8C, 11th floor, DLF cyber city, Gurgaon, Harayana, India. The sylvinite as processed products (sylvite in MoP form) from Shivi Products(Marketing: Flipkart) and saltpeter as Kalmi Shora from Neeraj Traders E-221, Purani Pasrat, Jhansi, Uttar Pradesh (2824002) (Marketing: amazon.in)was purchased online. **Glauconite sandstone** was Department of Geology (Prof. B.P. Singh, HOD), Institute of Science, Banaras Hindu University, Varanasi.

For characterization of the soil collected from Agricultural Research Farm of Banaras Hindu University, Varanasi district in Uttar Pradesh, various physical properties (colour, bulk density, particle density, water holding capacity and texture) and electrochemical properties (pH and EC) were analyzed using standard analytical techniques. Organic carbon and plant available macro-nutrients (N, P, K, S, Ca and Mg) were determined by using standard procedures.

The laboratory incubation experiment was laid out in a completely randomized design (CRD) with three replications. The soil was treated with different K-bearing minerals at the recommended dose of the banana crop (single dose and double the dose). The experiment was conducted under soil moisture at field capacity and at room temperature throughout the incubation period of different intervals i.e 5, 15, 30, 45, 60 and 90 days of incubation (DAI) for potassium release estimation and effect on K release from K-bearing minerals on soil pH and soil EC. The experiment's findings were subjected to statistical analysis in order to reach reliable conclusions.

The soil of Varanasi, Uttar Pradesh was sandy loam in texture and the colour of the soil was dark brown (10YR/4/3). The water holding capacity of the soil was quite high i.e > 40% suitable for plant growth. The pH of the soil was found to be neutral and the EC of the soil was less than 1.0 dSm^{-1}. The plant-available nitrogen was low, plant-available phosphorus was high and potassium was medium. The plant-available sulphur was low.

The four K-bearing minerals (high-grade: sylvinite, langbeinite and saltpeter and low-grade: glauconite) were applied to the soil at the recommended dose of banana, and the release of potassium from sylvite, langbeinite and saltpeter showed significantly higher release of K from 5 DAI to 90 DAI than control; whereas glauconite showed non-significant variation with control. The amount of water-soluble potassium released at 90 DAI, (in single dose) sylvinite showed the highest potassium release of (174.98 mg K^+/ kg) i.e 7.42 times greater than control (T1). The exchangeable potassium showed a relatively high potassium release from 5 DAI to 90 DAI. At 90 DAI highest exchangeable K release was observed for saltpeter (in single dose) i.e (460.10 mg K^+/ kg) which was 4.33 times of T1(control). The highest reserve of non-exchangeable K was for sylvinite at single dose i.e 1412.00 mg K^+/ kg was 1.20 times more of non-exchangeable potassium reserved by T1(Control). At 90 DAI highest cumulative release of potassium in soil was for langbeinite at single dose i.e 213.58 mg K^+/ kg and it was 4.53 times more than T1(control). The decreasing pattern for release kinetics of potassium was seen from 5 DAI to 90 DAI i.e 5 DAI > 15 DAI > 30 DAI > 45 DAI > 60 DAI > 90 DAI. At 90 DAI highest release kinetics was for langbeinite (at single dose) i.e 0.098 mg K^+/ kg soil /h and it was 4.66 times more than T1(Control). The pH for incubated soil showed the highest pH for glauconite (i.e single dose) from 5 DAI to 90 DAI where as other treatments i.e soil amendment with saltpeter, langbeinite and sylvinite and T1(control) showed relatively less pH change than glauconite. The EC of soil increased from 5 DAI to 90 DAI. Among all treatments (single dose of K-bearing minerals) langbeinite at single dose showed the highest EC from 5 DAI to 90 DAI and the highest EC of the soil at 90 DAI was noticed in langbeinite amended soil i.e 1.368 dSm^{-1} was 3.33 times more than T1(Control).

The salt index of sylvite was more than all other applied K-bearing minerals which mean sylvite has the highest salt accumulation (EC) but in this incubation and further study, it was observed that the high EC produced by langbeinite on the basis of soil conditions. The chloride of sylvite is responsible for the high-value salt index which is injurious to plant growth and seed germination and in the case of the salt index in langbeinite amended soil is due to the presence of sulphate ions (SO_4^{2-}) which do not harm plants as compared to sylvite. The glauconite showed slow release in normal soil but it could release a comparatively higher amount of potassium release of potassium in presence of organic acids or by treating glauconite nano-particles with organic acids.

Considering the release pattern and kinetics of the three tested high-grade K-bearing minerals, *viz*. saltpeter, langbeinite and sylvinite (sylvite) and low-grade indigenous K-bearing minerals i.e glauconite, and also their impacts on soil pH and EC, langbeinite should be the most suitable as K-bearing mineral fertilizers for the banana crop in the Inceptisol of Varanasi of neutral pH sandy loam soil. But in future, the technologies for solubilization of low-grade, poor soluble indigenous K-bearing mineral, glauconite should be developed to minimization of the foreign investment, such as addition of potassium solubilizing bacteria/fungi, organic acids and organic matter amendment with glauconitic, sandstone in soil.

BIBLIOGRAPHY

Ali, A., Zia, M. S., Hussain, F., Salim, M., Mahmood, I. A., and Shahzad, A. (2005). Efficacy of different methods of potassium fertilizer application on paddy yield, K uptake and agronomic efficiency. *Pakistan Journal of Agricultural Sciences*, *42*, 1-2.

Alori, E. T., Glick, B. R., & Babalola, O. O. (2017). Microbial phosphorus solubilization and its potential for use in sustainable agriculture. *Frontiers in microbiology*, *8*, 971.

Amorosi, A., Sammartino, I. and Tateo, F. (2007). Evolution patterns of glaucony maturity: A mineralogical and geochemical approach. *Deep Sea Research Part II: Topical Studies in Oceanography*, **54**(11-13): 1364-1374.

Anonymous, 2008-09, Fertilizers Statistics, *Fertilizer Association* of India, New Delhi.

Barré, P., Velde, B., Fontaine, C., Catel, N., & Abbadie, L. (2008). Which 2: 1 clay minerals are involved in the soil potassium reservoir? Insights from potassium addition or removal experiments on three temperate grassland soil clay assemblages. *Geoderma*, *146*(1-2), 216-223.

Basak, B. B., B. Sarkar, D. R. Biswas, S. Sarkar, P. Sanderson, and R. Naidu. (2017). Bio-interventions of naturally occurring silicate minerals for alternative source of potassium: Challenges and opportunities. *Advances in Agronomy* **141**:15–140.

Black, C.A. (1965). Methods of Soil Analysis, Part I, Physical and Mineralogical Properties of Soil, (including statistics of measurement and sampling) no. 9 in the series Agronomy, *American Society Agronomy*, Inc. Madison, Wisconsin.

Bolton, H.C. (1882). Application of organic acids to the examination of minerals. Proceedings of American Association of Advanced Science **31**: 3-7.

Bosecker, K. (1997). Bioleaching: metal solubilization by microorganisms. *FEMS Microbiology Reviews*, *20*(3-4), 591-604.

Bouyoucos, G.J. (1927). The hydrometer as a new method for the mechanical analysis of soils. *Soil Science*, **23**:343-353

Coroneos, C., Hinsinger, P., & Gilkes, R. J. (1995). Granite powder as a source of potassium for plants: a glasshouse bioassay comparing two pasture species. *Fertilizer Research*, *45*(2), 143-152.

Cox, A.E., Joern, B.C., Roth, C.B., 1996. Non-exchangeable ammonium and potassium determination in soils with modified sodium tetraphenylboron method. *Soil Science. Society of America Journal* 60, 114 – 120.

Fixen, P. E., and Johnston, A. M. (2012). World fertilizer nutrient reserves: a view to the future. *Journal of the Science of Food and Agriculture, 92*(5), 1001-1005.

Hao Z, Desi S, Hong B (2012) Adv Mater Res 524:1136

Hesse, P.R. (1971). A textbook of soil chemical analysis. London: John Murray

Hewedy, A.M. (2000). Effect of methods and sources of potassium application on the productivity and fruit quality of some new tomato hybrids. *Egyptian Journal of Agricultral Research,* **78**:227–244

Hosseinpur, A. R., and Motaghian, H. R. (2013). Application of kinetic models in describing soil potassium release characteristics and their correlations with potassium extracted by chemical methods. *Pedosphere*, *23*(4), 482-492.

Hosseinpur, A. R., Motaghian, H. R., and Salehi, M. H. (2012). Potassium release kinetics and its correlation with pinto bean (Phaseolus vulgaris) plant indices. *Plant, Soil and Environment*, *58*(7), 328-333.

Huang, W.H., and Keller, D.A. (1970. Dissolution of rock forming minerals in organic acids. *American Minerals* **55**: 2076-2094.

Jackson, M.L. (1967). Soil Chemical Analysis, Prentice Hall, Englewood Cliffs.

Jalali, M., and Ahmadi Mohammad Zinli, N. (2011). Kinetics of phosphorus release from calcareous soils under different land use in Iran. *Journal of Plant Nutrition and Soil Science*, *174*(1), 38-46.

Jena, S. K. (2021). A review on potash recovery from different rock and mineral sources. *Mining, Metallurgy & Exploration*, *38*(1), 47-68.

Kant, S., Kant, P., and Kafkafi, U. (2005). Potassium uptake by higher plants: From field application to membrane transport. *Acta Agronomica Hungarica*, *53*(4), 443-459.

Karimi, E., Abdolzadeh, A., Sadeghipour, H. R., & Aminei, A. (2012). The potential of glauconitic sandstone as a potassium fertilizer for olive plants. *Archives of Agronomy and Soil Science*, *58*(9), 983-993.

Kinekar, B. K. (2011). Potassium fertilizer situation in India: Current use and perspectives. *Karnataka Journal of Agricultural Sciences*, *24*(1).

Labib, B. F., Ghabour, T. K., Rahim, I. S., and Wahba, M. M. (2012). Effect of potassium bearing rock on the growth and quality of potato crop (Solanum tuberosum). *Journal of Agricultural Biotechnology and Sustainable Development*, *4*(1), 7.

Lalitha, M., and Dhakshinamoorthy, M. (2014). Forms of soil potassium-a review. *Agricultural reviews*, *35*(1).

Levchenko, E., Ptyk-Kara, N. and Levchenko, M. (2008). Glauconite deposits of Russia: Perspectives of development. In: Abstracts. International Geological Congress, Oslo, pp. 6-14.

Li, T., Wang, H., Wang, J., Zhou, Z., and Zhou, J. (2015). Exploring the potential of phyllosilicate minerals as potassium fertilizers using sodium tetraphenylboron and intensive cropping with perennial ryegrass. *Scientific reports*, *5*(1), 1-7.

Majumdar, K., Kumar, A., Shahi, V., Satyanarayana, T., Jat, M.L., Kumar, D., Pampolino, M., Gupta, N., Singh, V., Dwivedi B.S., Meena, M.C., Singh, V.K., Kamboj, B.R., Sidhu, H.S. and Johnston, A. (2012). Economics of potassium fertiliser application in rice, wheat and maize grown in the Indo-Gangetic Plains. *Indian Journal of Fertilisers* 8(5), 44-53.

Mohammed, S. M. O., Brandt, K., Gray, N. D., White, M. L., and Manning, D. A. C. (2014). Comparison of silicate minerals as sources of potassium for plant nutrition in sandy soil. *European Journal of Soil Science*, *65*(5), 653-662.

Mohnot, J. K., Prasad, V. V. R., and Verma, H. K. (2005). Investment opportunities for potash mining in India as an import substitute mineral. In *First Indian Mineral Congress and Technological Exhibition on Showcasing the Mineral Industry in 21st Century* (pp. 421-34).

Mustoe, G. E. (2018). Biogenic weathering: Solubilization of iron from minerals by epilithic freshwater algae and cyanobacteria. *Microorganisms*, *6*(1), 8.

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, A.L. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Circular No. 639. USDA.

Page, A.L. (1991). Methods of Soil Analysis, 2nd Edn. AM. Soc. Agron. And Soil Sci. America, Madison, Wisconsin, USA.

Palaskar, M.S., Barbrekar, P.G. and Ghosh, A.B. (1981). A rapid analytical technique to estimate sulphur in soil and plant extracts. *Journal Indian Society Soil Science*, **29**:249-256

Piper, C.S. (1951). Soil and plant analysis, University Adelaide, Australia.

Praveen, S., and Tomar, D. S. (2019). Solubility of Glauconite Nano-Particle in Root Exudates. *International Journal of Current Microbiology and Application Science*, *8*(6), 3315-3320.

Rader, L. F., White, L. M., & Whittaker, C. W. (1943). The salt index-A measure of the effect of fertilizers on the concentration of the soil solution. *Soil Sci*, *55*(3), 201-218.

Rakesh, S., Juttu, R., Kamalakar, J. and Raju, B. (2020). Glauconite: An indigenous and alternative source of potassium fertilizer for sustainable agriculture. *International Journal of Bioresource Science*, **7**(1): 17-19.

Rao, C. S., Reddy, S. B., and Kundu, S. (2014). Potassium nutrition and management in Indian agriculture. *Indian Journal of Fertilisers*, 58.

Sheng, X. F., Zhao, F., He, L. Y., Qiu, G., and Chen, L. (2008). Isolation and characterization of silicate mineral-solubilizing Bacillus globisporus Q12 from the surfaces of weathered feldspar. *Canadian Journal of Microbiology*, *54*(12), 1064-1068.

Shu-Xin, T. U., Zhi-Fen, G. U. O., and Jin-He, S. U. N. (2007). Effect of oxalic acid on potassium release from typical Chinese soils and minerals. *Pedosphere*, *17*(4), 457-466.

Song, S. K., & Huang, P. M. (1988). Dynamics of potassium release from potassium-bearing minerals as influenced by oxalic and citric acids. *Soil Science Society of America Journal*, *52*(2), 383-390.

Sparks, D.L., and Huang, P.M., (1985). Physical chemistry of soil potassium. In: Munson, R.D. (Ed.), Potassium in Agriculture. *Soil Science Society of America*, Madison, WI, pp. 201 – 276.

Sprengel, C. (1826). Uber Pflanzenhumus, Humussaure und Humussaure Salze. Kastners Arch. Naturlehre 8: 145-200.

Srinivasarao, C., Rupa, T. R., Subba Rao, A., Ramesh, G., and Bansal, S. K. (2006). Release kinetics of non-exchangeable potassium by different extractants from soils of varying mineralogy and depth. *Communications in soil science and plant analysis*, 37(3-4), 473-491.

Srinivasarao, Ch., Subba Rao, A., and Rupa, T.R. (2000) Plant mobilization of soil reserve potassium from fifteen smectitic soils in relation to soil test potassium and mineralogy. *Soil Sci*ence, **165**: 578–586.

Subbiah, B.V. and Asija, G.L. (1956). A rapid procedure for determination of available nitrogen in soils. *Journal of Current Sci*ence, 25:259-260

Tandon, H. L. S. (2004). *Fertilizers in Indian agriculture from 20th to 21st century*. Fertiliser Development and Consultation Organisation, New Delhi, India. pp 240.

Walkley, A. and Black, I.A. (1934). An examination of the Degtjareff method for determining soil organic method, and a proposed modification of the chromic acid titration method. *Journal of Soil Science*, 34:29-38

Welch, L.F., Johnson, P.E., McKibben, G.E., Boone, L.V., and Pendleton, J.W. (1966). Relative Efficiency of Broadcast Versus Banded Potassium for Corn. *Agronomy Journal*, 58(6), 618.

Zareian, G., Farpoor, M. H., Hejazi-Mehrizi, M., & Jafari, A. (2018). Kinetics of non-exchangeable potassium release in selected soil orders of Southern Iran. *Soil and Water Research*, *13*(4), 200-207.

Zörb, C., Senbayram, M., & Peiter, E. (2014). Potassium in agriculture–status and perspectives. *Journal of Plant Physiology*, *171*(9), 656-669.