UTILISATION OF POTASSIUM RICH CROP RESIDUES FOR RETENTION OF POTASSIUM IN LATERITIC SOIL

By

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(2019-11-010)

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THESIS

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2021

DECLARATION

I hereby declare that this thesis entitled "**Utilisation of potassium rich crop residues for retention of potassium in lateritic soil**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or society.

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Date: 29.11.2021

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CERTIFICATE

Certified that this thesis entitled "**Utilisation of potassium rich crop residues for retention of potassium in lateritic soil**" is a record of research work done independently by **Ms. Sreelakshmi P.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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"Dedicated to my beloved Achan"

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Introduction

1. INTRODUCTION

Agriculture is the cornerstone of the Indian economy. Even though Indian agriculture contributes 19.9 percent of Gross Domestic Product (GDP) in India, 64 percent of the population is completely dependent on agriculture. But, due to an exponential increase in population (1.9 percent per annum),food production (1.7 percent per annum) could not keep pace with the growing demand, which ultimately contributes to poverty and food insecurity. India has increased its total food grain production from 170 Mt (1990) to 252 Mt (2016) in the last 25 years and currently reached 305.2 Mt in 2020 (FAI,2020). But, given the common application of imbalanced nutrients in most of the crops of our country, each one of us can question if the adopted strategies of applying nutrients to achieve this increase in production were sustainable or not.

Even though fertilizer consumption and food grain production have shown an increasing trend, the ratio of nutrients used in our country has shown some general concerns. One of the major problems is the low use of potassium (K) in the crops. Several data for more than 50 years in India showed that potassium has contributed to less than 10 percent of the total fertilizer consumption (Majumdar et al., 2017). The quantities of N, P and K fertilizers applied over the period in Indian agriculture stated that the amount of K fertilizers were applied in much lower dose with wide ratios of NPK. From the 1960s to 2010, fertilizer consumption of N has increased from 1.4 to 85 kg/ha whereas K consumption has shown an increase from 0.2 to 18 kg/ha during the same period.This imbalance was created due to the dual pricing policy of the Indian government such that the cost of N and P fertilizers was maintained steadily but the price of K fertilizers was increased drastically and no subsidies were provided to it. The high K removal by crop than K addition and imbalanced use of NPK fertilizers has contributed to large-scale K mining and K deficiency in soils and crops. This has created an unawareness of the importance and benefits of K application in crops by farmers which has resulted in lower K status of Indian soils.

Along with increased cost, relying solely on inorganic K fertilizers has also resulted in soil organic matter losses, poor drainage, erosion, nutrient leaching and regional water contamination issues. Several studies have stated that K from crop residues can substitute for a portion of K fertilizers to fulfill crop requirements, reduce fertilizers expenses and enhance soil and crop benefits (Sui *et al.*, 2015). So in place of K fertilizers, organic K sources such as cereal straw, plantain waste, wood ash, compost, etc., are gaining more demand. Recent studies have stated that potassium ion solubilizes easily from plant residue materials into the soil solution due to its high mobility as a predominantly unbounded monoatomic cation in plant tissues. Various studies have reported that the application of rice straw, (which contains about 1.2 to 1.5 percent of K) could improve soil available K to a greater extent than manure. Plantain wastes including pseudostems, peels and leaves contribute a rich source of K to the soil. Plantain compost contains higher K content than the initial material which is mainly due to the reason that the composting process has enhanced the microbial population in the residues and subsequently enriched them with more plant nutrients (Suthar,2009).

The highly weathered and leached lateritic soils of Kerala, developed under humid tropics do not have any significant amount of K-bearing minerals. The mineralogy of these soils is predominantly composed of 1:1 type phyllosilicate and iron and aluminum oxides that can lead to severe K deficiency (Rheinheimer *et al.,* 2018). The cation exchange capacity of low activity clay minerals in the soils (mainly Kaolinite) does not permit the retention of the significant amount of potassium in exchangeable form. Maintenance of high levels of organic matter and reducing soil acidity through liming are recommended to regulate the potassium nutrition of plants in these soils (KSPB, 2013). It is known that liming increases potassium retention and reduces leaching losses. However, liming depresses the activity of solution potassium and induces lower potassium uptake by plants. Hence plants show potassium deficiency symptoms on freshly limed soils.

It is quite hard to apply pure chemical kinetics to heterogeneous soil systems since the work on the kinetics of potassium release is often restricted especially from different soil fractions of India. Therefore, studies have to be undertaken regarding the release of different fractions of potassium and to correlate such process with potassium supplying power of soil). Therefore, nutrient management practices that tackle the agricultural ecosystem process can strategically integrate mineral and organic K sources while building nutrient reservoirs. So the future of food security depends on our ability to increase yield and food quality using the soils that are already under production today. Therefore, healthy soils are the foundation of the food system. Thus, the present study entitled “Utilisation of potassium rich crop residues for retention of potassium in lateritic soil” has been undertaken with the following objectives:

- To study the decomposition dynamics of rice straw and K release from rice straw andplantain residue compost
- To determine the extent of the magnitude of K adsorption on rice straw under various incubation intervals and plantain compost
- To study the different forms of K in soil under application of rice straw, plantain compost and other K-rich organic sources alone and in combination with lime and potash.

Review of literature

2. REVIEW OF LITERATURE

Potassium has long been accepted as the versatile major nutrient, which is essential for normal growth and development for plants and animals.It was first discovered by Sir Humphry Davy in 1807. It is the seventh most abundant element in earth's crust constituting about 2.5 per cent of earth's crust (Sparks and Huang, 1985). The name potassium has been derived from an English word "potash", a slurry of plant ash and water from which element K was originally recognized.Potassium is essential for maintaining certain physical and chemical processes that are essential to sustain life and is ubiquitous in nature. In order to determine the dynamics of potassium in soil, the literatures available in India and abroad is reviewed as under;

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2.1 POTASSIUM AND PLANT GROWTH

When it comes to nutrients needed by plants, potassium comes second to nitrogen and considered as the "quality nutrient" due to its multifunctional role in plant metabolism. It activates more than sixty different enzymes and also plays important role in major processes like carbon dioxide assimilation, ATP synthesis, osmoregulation, maintaining water balance, reduce lodging, protein synthesis,cation-anion balance, lignification of sclerenchyma tissues, etc.(Haeder and Mengel, 1976). Potassium also increases the leaf area, chlorophyll content and delay senescence, thus contributing towards greater canopy photosynthesis and plant growth. Its luxurious consumption helps the plant to withstand stress such as disease and pest attack, drought and frost condition. The concentration of K in plants cell sap generally ranges between 100 to 200 millimoles of K^+ (Beringerand Nothdurft, 1985). Therefore, potassium is the most important inorganic osmotic component that enhances growth primarily by its effect on cell extension.

Potassium improves both quality and quantity of plant life. No plants can complete their life cycle without its uptake. Potassium uptake by plants is a dynamic process with different levels of K depletion in the root zone and release of non-exchangeable K to exchangeable and water soluble fractions by K bearing minerals (Havlin *et al.,* 1985). Plant's roots absorb potassium as univalent cation which is freely mobile in both plants and soil. Generally field crops absorb potassium faster than nitrogen or phosphorous but the rate of absorption varies with crop growth stages and their conditions (Patel *et al*., 1993). Most of the cultivated crops such as banana, tobacco, potato, onion, grapes, sugarcane etc. absorb potassium far higher than nitrogen and its deficiency results in decrease in grain yield and growth (Caporn*et al*., 1982 and Veerkamp and Kupier, 1982). From the middle of 17^{th} century when Johann Rudolf Glauber proposed that saltpeter (KNO_3) was the principle of vegetation, from then onwards potassium has been recognized as one of the important essential nutrient for plant growth.

2.1.1 POTASSIUM DEFICIENCY SYMPTOMS IN PLANTS

The most common symptoms of potash deficiency in plants are (i) chlorosis along the leaf margins followed by scorching and browning of tips in older leaves (ii) slow and stunted growth (iii) weak stalks and susceptibility to lodging, pests and disease incidence etc., (iv) low yield and productivity (FAO, 1984).

Each crop has its own characteristic symptoms that determine their K deficit. By the time the symptoms of K deficiency appear, potato yield could be reduced as much to 50 per cent (Singh, 1976).

Potassium is being taken up by plants in large quantities which is influenced by soil K status. In India, normally 40-60 kg K_2O ha^{-1} is recommended for application to different crops, which is far less than the amount of K removed by cereals like rice and wheat, particularly when crop residues are not returned to the soil. That is why in most of the cropping systems a negative K balance between soil-plant systems exist, especially under intensively cultivated regions due to high productivity (Yadav *et al.*, 2001). Potassium balance in intensive rice-wheat cropping systems in India amounted to -141 to -61 kg K_2O ha^{-1}. Srinivasarao and Satyanarayana (2012) found that the overall negative balance of K in Indian soils is estimated at 303 mt K y^{-1}.Due to high plant requirement and inadequate supply, a decrease in crop productivity has been reported even in K rich soil orders like Mollisols and Vertisols (Srinivasarao*et al.*, 2014). Therefore, the negative K balance impact the soil's ability to supply K by affecting different forms of potassium.

2.2 SIGNIFICANCE OF POTASSIUM IN HUMAN HEALTH

The importance of potassium to human health has been well acknowledged because it is the principal electrolyte in the intracellular fluid that takes part in acid base balance, osmoregulation, conduction of nerve impulses, contraction of muscles, cell membrane functions and many more. Potassium also functions in protein synthesis, carbohydrate metabolism and also prevent the risks of diabetes and kidney problems. The average daily consumption of K through diet is about 3400 mg for men and 2600 mg for women on daily basis (NASEM, 2019). It is well known that plant nutrition and food safety are closely related. Therefore, good management of potassium nutrition can contribute to gain in crop productivity, nutritional quality as well as health related quality of human life.

2.3 IMPORTANCE OF POTASSIUM IN SOIL

In soils, the major sources of K are mainly contributed by minerals such as feldspars (mainly by orthoclase) and micas (biotite and muscovite) which are found in the coarse fractions of soil that would release the mineral in the course of weathering and are later available to plants (McGrath *et al.*, 2014). But in the case of fine fractions like silt and clay, potassium is chiefly present as interlayer K in the illite minerals (Jackson, 1964). The rate and the extent in which potassium get released from these minerals also depend upon their susceptibility to weathering (Schroeder,1978 and Venkatesh and Satyanarayana, 1994), temperature (Quirk and Chute, 1968), nature and concentration of extractant (Fanning and Keramides, 1977) and the concentration of potassium in extracting solutions. But in the case of soil orders like Ultisols and Oxisols theyexhibitprolonged weathering due to intense rainfall, they show K deficiency due to leaching so that these soils require addition of K in the form of fertilizers. Soils that contain large quantities of vermiculite and mica could have huge amount of non-exchangeable K while soils containing high amount of quartz, kaolinite and other siliceous minerals contain lower amounts of available and exchangeable K (Martin and Sparks, 1985). Therefore, status of potassium in soil has been determined based upon the content of K bearing minerals in soil since their presence would give some demonstration about its potential availability to plants (Sparks, 1987). Mobility of nutrient K in soil is low because of greater affinity with exchangeable sites of clays.

2.3.1. POTASSIUM STATUSOF INDIAN SOILS

The total average potassium content in the lithosphere comes about 3.1 per cent K_2O and potassium content in Indian soils variesfrom 0.5 to about 3.0 per cent (Tandonand Sekhon, 1988). Out of this, 98.0 per cent of total potassium is bound in mineral form, while about 2.0 per cent is in soil solution and exchangeable bases.

Generally alluvial soils of India were rich in potassium (Ghosh and Hasan, 1976). But the distribution of different forms of potassium in these soils is a function of nature of parent material and their rate of weathering. The amount of K in the soil varies widely depending upon different factors such as parent rock material, intensity of weathering, climatic condition and cropping history.

The scenario of potassium status in India is changing day by day. It was assumed that potassium is in sufficient amount in the Indo-Gangetic plains of Punjab and Haryana but, later studies reported that potassium status has started to decline because of its excess removal from soil due to extensive cropping systems that have been followed.Raj Bhatt and Manoj Sharma (2011) reported that around 65.0 per cent of 2026 soil samples collected from Kapurthala district of Punjab showed decline in K status (K< 137.5 kg ha^{-1}).

Sekhon and Singh (1982) had mapped the Indian soils based on soil test and critical values of K, reported that 20.0 per cent soils were low in available K, 42.0 per cent soils were medium and 38.0 per cent soils were in high range.

From the research studies conducted by Ramamurthy and Bajaj (1969), Ghosh and Hasan (2002) and Naidu *et al*., (2011) regarding K status of Indian soils reported that the general trend has been moved from medium to high status in the year 1976, to medium to low in 2002.Because of intensive cropping systems, those soils that are now having moderate to high exchangeable potassium are probably to become certainly potassium responsive (Mittal *et al*., 1990). They also described that exchangeable K get fixed at a particular level known as minimum level.When it reaches under such level, the nutrient has to be supplied entirely from non-exchangeable form which constitute about 90.0 per cent of total potassium uptake (Biswas, 1974 and Singh, 1979).

From the experiment conducted under AICRP program of ICAR (Brar and Pasricha1998) noticed a decreasing trend in K status from high to medium to low content mainly due to intensive cropping with the introduction of high yielding varieties.Recently, scientists from the Indian Institute of Soil Science and Tamil Nadu Agricultural University (Dey, *et al.,* 2017) have combined their reports to highlight the potassium status of Indian soils and came up with a conclusion that, the percentageof soils per district under low and medium K fertility categories are far higher as compared to high and very high categories.

Texture of soil is also a prominent factor that determines the K status of soil that increases with increase in fineness of soil (Sekhon and Subba Rao, 1985). Sharma and Mishra (1986) observed that alluvial soils of western U.Pwith clay content was having highest potassium content as compared with silt and sand but they observed a reverse order in contribution towards total potassium content because of low clay content in these soils and they further discovered that coarse textured sandy soils had higher content of water soluble K whereas, exchangeable and non-exchangeable forms of K were higher in fine textured clayey soils.Sadusky*et al.,* (1987) reported that the release of potassium from the sand fractions was mainly due to the presence of highly weathered potassium feldspar in the soils and potassium release was a surface reaction. Soils with higher clay content take lesser time than the soils with lower content of clay to adsorb the same quantity of potassium. Mehta and Singh (1986) reported that slow rate of adsorption was due to high amount of Illite and traces or absence of Kaolinite content in soil. Singh (2016) came up with the conclusion that coarse textured soil would deplete soil K faster than fine textured soil. Therefore,constant monitoring of potassium level in soil is essential.

A large number of literature that support potassium release rate has been noticed for relatively acidic and highly weathered potassium responsive soils of moderate to high rainfall areas. From the study conducted by Kadrekar and Kibe (1973) regarding the potassium release from soil of different degree of hydration and drying revealed that in moist condition, potassium release occur only at the end of 50 to 60 days. It was observed that lower moisture level (half of the field capacity) favoured the release of soil K. It is therefore crucial to have information about rate of non-exchangeablepotassium release in the soil.Singh and Dutta (1986) observed that potassium content in soil decreased with decrease in latitude.

2.3.2 POTASSIUM STATUS OF KERALA SOILS

Major parts of southern India are occupied by red and laterite soils which are generally considered as potassium deficient (Ramanathan and Krishnamoorthy, 1978; Sekhon and Subba Rao, 1985). Brar*et al.* (1986) had studied the potassium status of surface soils of five benchmark series broadly arised in the states of Andrapradesh, Tamil Nadu, Karnataka and Kerala and reported that soils of Nedumangad (laterite), Vijayapura and Tyamagondlu (red) were low in available and reserve potassium.Bastin and Venugopal (1986) estimated the nutrient status of some red soils (Alfisols) collected from different regions of Kerala and reported that the available K status was highest in Chirakkal series that varied from 12.09 to 113.58 ppm and lowest content was observed in Kunhimangalam series. They also reported that soil order Alfisols, that are considerably cultivated for coconut had low to medium K status.

Nair (1973) noticed low status of N, P, K in red soils of Vellayani area and this occurred mainly due to low organic matter content and low cation exchange capacity of these soils. Pillai (1975) stated that all the soil groups of Kerala under coconut cultivation were generally deficit in available K and no soil groups come under high ratings. Devi *et al.*, (1990) conducted study with two soil series of South Kerala (Vellayani and Neyyattinkara) to determine different forms of K and reported that water soluble K was significantly correlated with available and exchangeable forms of potassium.

In common, potassium status of Kerala soils is low due to humid tropical climate with intense leaching and weathering (Louis joseph, 1994).In 1976, K status of Kerala was medium in 56 per cent area and low in 44 per cent area, while in 1999, the trend showed an increase in low (62 per cent) and medium (31 per cent) categories respectively (NBSS and LUP, 1999). Rajasekharan*et al.*, (2013) conducted a fertility assessment of Kerala soils and reported that 33 per cent and 31 per cent area was under medium and high range respectively. A statistical analysis was conducted by some scientists of Indian Institute of Information Technology and Management, Kerala, regarding soil fertility assessment of Thrissur district and found that potassium content varied from 79.2 ppm to 473.8ppm with a mean of 252 ppm which indicated K deficiency (Kumar *et al.,* 2016).

2.4. DIFFERENT FORMS OF POTASSIUM

The total potassium exists in soil under different forms such as, water soluble K, available K, exchangeable K,non-exchangeable K and mineral K all of which are in dynamic equilibrium with each other and depletion in any given form is likely to shift the equilibrium in the direction to reload it (Ramamurthy and Bajaj, 1969). Among these forms, approximately 98 per cent of total potassium is bounded in soil as mineral and non -exchangeable forms and the remaining 2 per cent consists of solution and exchangeable forms (Sekhon, 1995).

Presence of dynamic equilibrium between these different forms of potassium was also reported by (Gupta *et al.,*1983).All these forms are interrelated by an equilibrium in which increase in one form occurs at the expense of one or more other forms and the net movement occurs from less available to more available state or vice versa, depending on particular condition (Reitemeier, 1951).So these equilibrium reactions affect the levels of available potassium in soil at any time, which is the main form of potassium that has been taken up by plants (Sparks, 1987).

The availability of different forms of soil K towards microorganisms and plants are in the order: solution K> exchangeable K> non-exchangeable K> mineral K (Sparks and Huang, 1985). So an equilibrium exists between these forms of soil K.The fractional studies of soil K are having prime importance because 80 % of total K requirement of plants are satisfied by non- exchangeable form of soil K (Srinivasa Rao and Khera, 1994).

2.4.1. TOTAL K

Generally, higher amount of total K is observed in fine textured soils than the coarse textured soils. Due to predominance of potash bearing minerals, alluvials soils have higher content of total potassium. Comparing both surface and subsurface soils, total K content is more prolonged in subsurface soils. Total K content in different soils varies widely.

Scheffer*et al.* (1960) studied the potassium economy and mineral status of Gottingen E plot and found that 41.8 per cent of the total K was present in the fine fraction as a component of mica while 28.2 per cent was found in the clay fraction as interlayer K in the illite type of clay mineral.After studying some benchmarks soils of north-west India, Dhillon *et al.,* (1985) reported that the amount of total K was more prolonged in sub surface layer of soil than surface soil. Prakash and Singh (1985) reported that the amount of total potassium present in the alluvial soils of western U.P ranged from 0.60 per cent to 2.80 per cent with mean value of 1.37 per cent.The content of total K in Mizoram soils varied from 1.96 per cent to 3.84 per cent with a mean value of 2.70 per cent (Singh and Dutta, 1986). But, Kanwar and Singh (1989) noticed that citrus orchard of U.P hills had total K content varied between 17000 ppm to 34000 ppm. Pal and Mukhopadhyay (1992) stated that the depth wise dissemination of potassium was not systematic and differed with soil texture.

Deshmukh and Khera (1990) estimated the potassium supplying power of 11 Ustrochrepts and stated that the total K uptake came from the non-exchangeable K of soil.The total K content present in the calcareous soils of Gujarat ranged from 1.10 to 20.30 cmol kg^{-1} soil (Golakiya*et al.*, 2001). Total K content in soil did not have any remarkable significant relation with soil properties (Singh,2016).

2.4.2 NON- EXCHANGEABLE K

Non exchangeable form of K are firmly held in the negatively charged interlayer surface sites (Kittrick, 1966). It is different from that of total K is that it is not covalently bonded within the crystal structure of soil mineral particles. Rich (1972) stated that non exchangeable K is generally held between adjacent tetrahedral layers of dioctahedral or trioctahedral micas, vermiculites and intergraded clay minerals. The potassium that are held at inter lattice position is non exchangeable K and they cannot be extracted with ammonium acetate extract (Ramamoorthy and Velayudham, 1976). They are not easily available to plants but they maintain equilibrium with available forms and accordingly they act as an important reservoir of slowly available K (Perkins, 1976).Barber (1979) stated that non exchangeable K is equated to fixed potassium where it is present in the random gaps in the structure of amorphous clay minerals. That is why, the potassium cations are physically confined to various degrees, thus making K release, a rate limiting component (Martin and Sparks, 1983).

Non exchangeable K are sometimes also referred as “interlayer K” or “fixed K” or “slowly exchangeable K” or “slowly available K”. The highest amount of non-exchangeable K was reported in black soils followed by alluvial and red soils (Ekambharam and Kothandaraman, 1983). Since the variability in non-exchangeable

K is low, it could be used as a foundation to determine different soil series (Subba Rao and Sekhon, 1990).

Non exchangeable K content ranged from 1.11 to 6.80 m. e / 100g of soil with a mean value of 3.92 m. e / 100g of soil (Dhillon *et al.*, 1985). Bandhopadhyay*et al.* (1985) also noticed that coastal soils of Orissa contained higher amount of non – exchangeable K which ranged from 1300 kg ha^{-1} 9707 kg ha^{-1}.

When available and exchangeable potassium got exhausted through crop removal and/or leaching, Non exchangeable K prone to be released (Maurya and Ghosh, 1972 and Sparks, 1980). It is the principal aspect of the potassium transformations in soil under rice-wheat cropping systems is the rate at which non exchangeable form get transformed to available and exchangeable form. Martin and Sparks (1985) reported that the amount and rate of release of non-exchangeable form mainly depends on the amount of potassium in soil solution along with the type and quandity of clay minerals present.

The amount of non-exchangeable K form in soils differ widely (Basumatary and Bordoloi, 1992). This form of K constitutedabout 10.91 per cent of total K and also had remarkable relationship with it (Pal and Mukhopadhyay, 1992).Sekhon*et al.* (1992) reported that soils of Punjab, U.P and Bihar which were rich in illite type of clay mineral contained 1330 to 2200 mg kg^{-1} of non-exchangeable potassium whereas soils from West Bengal that containedsmectite and kaolinite type of clay minerals contained 601 and 98 mg kg^{-1} of non-exchangeable potassium in soil.

The rate of release of this fraction is also determined by the degree of exposure of edges of clay minerals to the solution and its position with respect to outer edges. Therefore, the liberation of non-exchangeable K might be slow enough to limit the yield whereas, it might be fast enough to meet the potassium need of the entire crop. Bansal *et al.* (2002) reported that non-exchangeable K contributed more towards total K in alluvial and black type soils than red soils.

2.4.3. AVAILABLE K

Available K constitutes water soluble and exchangeable K. So those factors that causes changes in water soluble and available K, too have effect on available K status in soil. Kanwar and Singh (1989) reported that the amount of available K constituted about 0.28 per cent of total K and 1.4 per cent of lattice K and 9.6 per cent of fixed K. Samra and Swarup (2002) noticed that many long term experiments over the country has also showed considerable decrease in available K with time.

Apart from this, native K also become available due to effect of organic acids released during decomposition (Dhanorkar*et al.,* 1994). Lal *et al.* (2000) delineated that with increased incubation time of soil, K mineralization also increased significantly and raised the available K pool in the soil due to release of more organically bounded potassium in due course of decomposition of organic waste materials.

Brar*et al.* (1998) also observed increased availability of K content in mannured soil than unmannered soils.Organic K sources like vermin compost and azolla is not only the source of available K but also increases cation exchange capacity of soil by expanding organic surface capable of ion exchange, thus results in an increase in exchangeable and plant available K (Blake *et al*., 1999).The increment in available K was not only due to application of K enriched organic matter. Rani *et al*. (2020) observed that addition of organic materials has maintained significant amount of available K for longer period of time and get exhausted at a slower rate in comparison to treatments with only K fertilizer.

Bandhopadhyay*et al*. (1985) reported that the amount of neutral normal ammonium acetate extractable potassium varied from 280 to 1309 ppm from the coastal regions of Orissa while Singh *et al.,* (1985) after studying the soils of western Haryana state observed that the amount of available K ranged from 16 to 97 ppm.

The amount of available K was relatively higher in lateritic soils than alluvial (Basumatary and Bordoloi, 1992). The reason for higher value in lateritic soils might be probably due to weathering of potash bearing minerals and due to release of soluble potassium from insoluble compounds. Presence of higher amount of clay in lateritic soils opposite to alluvial soils might have played an important role in increasing the amount of available K in soil by holding more amount of K in exchangeable form, thus preventing it from leaching. Yadvinder Singh and Bijay Singh (2001) reported that the critical levels of ammonim acetate extractable potassium could varied from 39 to 156 mg kg^{-1}, depending upon the soil texture, clay minerology and potassium input from natural resources.

2.4.4. EXCHANGEABLE K

It is one of the form of available K that is easily exchanged with other cations and readily available to plants. It is electrostatically bonded as outer- sphere complex to the surface of clay minerals and humic substances. The amount of exchangeable K accounts for about 90 per cent of available K and its percentage to total K is below 2 per cent (Schroeder, 1978).

The amount of K reserves and the rate of movement of exchangeable form determines the K supplying power of soils. Reitemeier (1951) stated that it is difficult to determine exchangeable K experimentally due to dissolution of mineral K by exchangeable extractants, absence of distinct difference between exchangeable and solution K and existence of difficulty extractable K that were not quickly extractable with any usual reagents. The potassium confined in the wedge-shaped interlayer spaces is exchanged quickly only by small ions like NH_4^+ or H^+ through proton or H-bond transfer (Rich and Black, 1964; Singh *et al.*, 1987).

Nash (1971) reported that exchangeable potassium actually is the total of potassium on the planar surfaces and that on the high energy specific sites. The fraction of exchangeable potassium greatly depends on the soil structure and the content increases with fineness of soil (Ranganathan and Satyanarayana, 1980 and Tarafar and Mukhopadhyay, 1989).

Normally, exchangeable K constituted about 82.4 per cent of available potassium (Singh *et al.,* 1983). Subba Rao *et al.* (1984) stated that clay fractions of soil contained more amount of exchangeable K than sand and silt fractions. Exchangeable fraction constituted about 1.1 to 2.0 per cent oftotal K in soil (Sharma and Dubey, 1988).Sharpley (1989), reported that solubility of exchangeable K increased from smectitic to kaolinitic soils. That is why kaolinitic soils were more depleted of their exchangeable K compared to smectitic soils. Exchangeable K determines easily available K but it fails to determine long term ability of soil to release potassium (Cervantes and Hanson, 1991).

Exchangeable K could also give a better manifestation of the potential K supplying power of a soil and also used for making recommendations of potassic fertilizers to the crops (Sharpley, 1989).Sharma *et al*. (2009) reported that the higher contribution of exchangeable K to surface than subsurface soil might be due to addition of K through plant residues, manures and fertilisers.

Yaduvanshi and Swarup (2006) from their studies reported the presence of larger amount of exchangeable K in FYM treated soil over years may be due to the reason that addition of FYM could enhance the CEC of the soil thus responsible for holding more amount of exchangeable K from Non- exchangeable pool. Singh *et al* (2010) reported that the content of exchangeable K constituted around 0.64 per cent of total K with values ranged between 49 to 304.2 mg kg^{-1} with a mean value of 93 mg kg^{-1} from the soils of Agra district in U P.

2.4.5. WATER SOLUBLE K

It is the quantity of potassium that exists under any given time that is dissolved under soil water suspension under normal moist field condition and are relatively unbounded by exchange forces are known as water soluble (soil solution) K (Reitemeier, 1951). From the study conducted by Prabhakumari (1981) reported that the amount of water soluble K in red and lateritic soils of Trivandrum district were in the range between 1.53 and 7.56 meq L^{-1}. The amount of water soluble K under normal condition of Indian soils ranges from 7.8 to 39ppm

Water soluble K accounts for about 5.7 to 20.6 per cent of available K content in different regions of West Bengal (Pal and Mukhopadhay,1992).

Tandon and Sekhon (1988) reported that water soluble K of intensively cultivated regions of India is about 0.2 per cent of total K and lies between 4 to 125.6 mg kg^{-1} in Indian soils.

Normally water soluble K content would be present more in surface soils than subsurface. But, from the findings of Sharma *et al.* (2009) reported that water soluble K accounted for about 0.2 per cent of total K in surface soils that depicted almost minor contribution towards total K in soils. The practicable reason might be due to upward translocation of K by capillary rise.

Rani *et al.* (2020) conducted an incubation study to determine different forms of K and observed that treatments with organic resources alone or in combination with fertilizers released K after a period of time due to decomposition of organic material and maintained water soluble K content of the soil, which is easily available to plants. Organic matter during their course of decomposition produces sufficient amount of organic acids which might have tendency to break down the potassium present either in mineral or non- exchangeable form thus bringing it into water soluble form.

Due to relatively high solubility of potassium applied through fertilizers, water soluble K are almost quickly removed from soil solution by adsorption and plant uptake.

2.5. EFFECT OF LIME APPLICATION ON POTASSIUM AVAILABILITY

Liming is defined as the application of mineral calcium and magnesium compounds mainly composed of carbonates, oxides, hydroxides or a mixture of them, more rarely silicates into acidic soil to reduce the concentrations of protons (McLean, 1971 and Miller *et al.,* 1995). Limed soils usually found to retain more potassium than acids soils (Mehlich, 1943). This can be represented as a benefit in long run since leaching losses get reduced. However, the increased retention of potassium by soil colloids after lime application is thought to be the reason that plants often show K deficiency on freshly limed soils (Bartlett and McIntosh, 1969). This shows that limed soil retains more non-exchangeable form of potassium.

Evans and Attoe (1948) reported that increased application of lime to acid soils would increase the amount of non-exchangeable (fixed) K and would cause decline in exchangeable form.A study was conducted by Kabeerathumma and Biddappa (1975) to determine the effect of different levels of lime application on exchangeable potassium under two acid sulphate soils of Kerala (Kari and Karapadam). They reported that the amount of exchangeable K decreased greatly in both soils with different doses of lime application upto 75^{th}day of incubation and they concluded that it might have converted to non-exchangeable form of potassium. Powell and Hatcheson (1965) also reported that the decrease in K at the planar exchange site would have been compressed into the non-exchangeable interlattice site which are not easily been exchanged.

2.6. TREND IN CONSUMPTION OF POTASSIUM FERTILIZERS IN INDIA

Potassium is considered to be one of the three main pillars of balanced fertilizer use together with nitrogen and phosphorous. In India, until 1980s, application of potassium did not receive much attention because of the common belief that Indian soils were rich in potassium and a profitable feedback of applied K was not always being observed so as to warrant blanket application (Ghosh and Hasan, 1976). Potassium (K) fertility status of Indian soils were estimated from different states and categorized Indian agricultural soils accordingly as 21 per cent low, 51 per cent medium and 28 per cent high, thus revealed that 72 per cent of Indian's agricultural area representing 266 districts need immediate K fertilization (Hasan, 2002).Although, India being the third largest consumer of NPK fertilizers in the world with annual consumption of about 18 million tons of N, P_2O_5 and K_2O, K accounts for only one seventh of the total amount (Hasan, 2002). Because, nutrient management in India is mainly driven by nitrogen followed by phosphorous and very little by potassium. Because of this general belief, Indian farmers has also neglected the use of K fertilizers. Singh (2015) conducted a survey with small, marginal and large scale farmers of India and reported that all of them covering more than 10 cropping systems invariably used far lesser amounts of K compared to N and P. But, reality remains that not all Indian soils have abundant supply of K bearing minerals and the presence of these minerals in the soils does not necessarily mean that the crops are getting the required amount of potassium at the right time (Sanyal*et al.*, 2014 and Manjumdar*et al.*, 2016). Application of lower amount of K fertilizers to crops has resulted in much higher uptake and removal of K from the soils that has led to K mining. Many scientific evidences have showed that application of suboptimal or no K has reduced crop productivity that has resulted in reducing farmer's income and induced mining of native reserves of potassium which caused detrimental effect on soil health and K fertility status.

There was a drastic increase in fertilizer consumption in India since the advent of Green Revolution in mid 1960s from less than a million tonne to 27 million tonnes in 2018-19, becoming the second largest fertilizer consuming country. But the sequence of fertilizer usage has been deformed with increasing imbalance in the use of primary nutrients viz, N (nitrogen), P (phosphorous) and K (potassium).

Current NPK use ratio is 7:2.7:1 as against to advisable ratio of 4:2:1. Because of this non judicious use of fertilizers, government of India had implemented a Task Force on Balanced Use of fertilizers in 2006, to adjust the pricing and subsidies on plant nutrients through restoration of the NPK ratio at macro level by increasing the use of nutrients like P and K instead of reducing the N intake, specifically with respect to the soil, plant and climate. But this step taken by the government was proved as insufficient to promote balanced use of plant nutrients. Because, there was a stagnant decrease in the price of urea that has completely attracted the farmers to buy and also use it as a substitute for others. The second reason was that, the fixed subsidy on K fertilizers were brought down that has led to steady increase in the retailing price that is barely affordable by the large scale marginal farmers. As per the latest data, the retail price of urea in India is US dollar 80 per MT which is only one by fourth of value of China and USA. The current price of Urea is Rs. 240 per 50 kg bag which is only one by fourth of value of MOP (Rs. 875 per 50 kg bag).Because of this increased consumption of Urea from 26 million tonnes to 32 million tonnes in 2018-19, farmers have preferred to use more of cheap urea at the cost of P and K fertilizers. This has resulted in the net negative NPK balance of 19% N, 12% P and 69% K. This large proportion of K is because crop removes about 1.5 times more K than N and its application through fertilizers is lower due to hike in price.In spite of having the world's largest reserves of potash in Rajasthan, our country has failed to scrutinize this huge deposit even after 45 years of its discovery costing about US dollar 1400 million every year to import potash that has caused due to negligence and abnormal delay in bringing up these huge deposits for commercial exploration.

It is very prominent that nutrient use pattern in most of the agriculturally important states of India are scarce and are mainly dominated by NP fertilizers. It's been observed a negative balance of K to an extent of about 3 million tons annually due to suboptimal use of potassic fertilizers (Srinivasarao*et al.*, 2010). Therefore, refinement of balanced use of K is required by switching over to organic K rich sources in order to maintain soil fertility and nutrient balance for higher productivity.

2.7. ORGANIC POTASSIUM SOURCES - AN ALTERNATIVE FOR POTASSIC FERTILIZER

Nowadays, organic sources such as cereal straw, plantain wastes, wood ash, compost etc., are gaining more demands. India produces about 500 million tonnes of crop residues per year from which, major contribution is from rice (43 per cent), wheat (21 per cent), sugarcane (19 per cent) and oilseed crops (5 per cent) (Jain *et al.*, 2014).Ramesh singh (2019) stated that burning of 1 tonne of straw release about 2 kg sulphur dioxide, 3 kg of particulate matter, 60 kg of carbon monoxide, 1460 kg of carbon dioxide and 199 kg of ash along with the nutrient loss of 5.5 kg of nitrogen, 1.2 kg sulphur, .3 kg phosphorous, 25 kg potassium and 400 kg organic carbon.

Cereal straws usually have a higher content of K content compared with other straws (1.02 -1.7 %). According to Economic Survey report (2013), India grows about 44.0 million ha of rice and 29.9 million ha (mt) of wheat which yields about 2.4 and 3.1 t ha^{-1} respectively. Our country produces about 104 mt of rice and 250 mt of rice straw annually out of which 24 mt are produced from Punjab and it is reported that more than 80 % of the rice straw that has been produced is burnt in the fields.

Mishra *et al.* (2001) reported that burning of rice straw apart from causing environmental pollution, also resulted in the loss of organic matter, N (100 %), P (20.1 %), K (19.8 %) and S (80.2%) respectively. Therefore, it is crucial to manage the rice straw rich in K, for enhancing soil health and crop productivity without degrading the environment. According to Ladha*et al.* (2003), studies conducted in the past suggested that insufficient supply of K may be might be one of the reason that limit sustainable production in the Indo- Gangetic plains.

Therefore, recycling of rice straw s often recommended to reduce K mining in soil. But in most cases, straw is either removed for alternative uses such as cattle feed and fuel or burnt in situ.From the studies conducted by Srinivasarao*et al.* (2010) showed that long-term incorporation of organic sources either alone, or in combination with fertilizers had increased the ammonium acetate extractable K form in alfisols and aridisols orders in India. Singh *et al*. (2001) also noticed that use of FYM with nitrogen fertilizers had enhanced the available K content in the soil.Dobermann and Fairhurst, (2012) reported that straw removal without enhancing K fertilizers has been found to intensify K deficiency in soil

Banana residues are more commonly available agriculture wastes. It has been estimated that global banana edible production is estimated to be about 102 million tonnes and Indian occupied more than 11 per cent of world's area under banana cultivation and also accounted for 31 per cent of global banana production (Pappu *et al.,* 2015).

Mostly it has been seen that banana wastes are incinerated. Rather than burning, banana psuedostems, rotten banana and other banana residues can be converted into compost as potential manure and It was reported that compost prepared from these wastes contained about 0.91 per cent N, 2.2 per cent P and 5.5 per cent K with C/N ratio of 23:1 (Alexander *et al.*, 2010).Kavitha*et al*. (2011) reported that the vermicompost produced from banana wastes with cow dung and *Eudrilius eugeniae* enhanced the microbial population and humic acid content more than natural compost that has resulted in improved soil fertility and crop productivity.

After the harvest of the fruit a large quantities of crop residues such as banana leaves, psuedostems and trashes are left over in the field containing as much as nutrients as in the harvested fruit. Doran and Kavya (2005) reported that one tonne of banana crop residue contains 15 kg N, 7 kg P and 23 kg K which showed its potential to be used as a K rich organic source. Mawahib*et al.* (2015) reported that compost prepared from banana crop residue is a cheap source of many nutrients, enhances organic matter and water holding capacity of soil, stimulates microbial life and increase the crop yield. Mayadevi*et al*. (2017) reported that the banana plants treated as plantain compost produced significantly higher and comparable values for quality parameters and also increased shelf life than that of mineral fertilizers with FYM.

Wood ash is actually the residual material formed when wood is burnt for energy production. It is one of the useful soil amendment because it enhances the soil pH and supplies vast number of nutrients. Among different nutrients, calcium is the most abundant element followed by potassium, phosphorous and magnesium and also gives ash properties that are similar to lime. Generally, wood ash has a good property of acid neutralizing capacity and contribute a wide range of minerals nutrients to soil. Along with liming effect, addition of wood ash to soil also enhance available potassium and phosphorous to soil (Erich, 1991).Ohno and Erich (1992) conducted an incubation study to determine phosphorous and potassium availability in wood ash amended soils and they concluded that application of wood ash had increased pH rapidly in the initial period of time and later pH had declined after 10 to 25 weeks. They also stated that availability of P and K to plants increased for the first 25 weeks and then decreased with time. The study also reported that P released from wood ash got quickly sorbed by the soil surface whereas, K remained in solution form. So the application of wood ash would increase the availability of P and K relatively for short period.

Materials and Methods

3. MATERIALS AND METHODS

The present research work entitiled "Utilisation of potassium rich crop residues for retention of potassium in lateritic soil" was conducted at College of Agriculture, Vellanikkara during the year 2019-2021 with the objective to determine potassium supplying power of major organic K rich sources like rice straw and plantain compost to soil thus reducing the use of expensive potassic fertilizers. The present study consisted of decomposition study of rice straw and their K release, K sorption rate from rice straw and plantain compost and incubation study to determine different forms of potassium from different sources.The physico-chemical properties of rice straw and plantain compost were initially taken and later on decomposition dynamics of rice straw was analysed at different intervals along with its K release rate. Potassium sorption study was conducted using different concentrations of KCl and incubation study was conducted by mixing soil with different potassium rich sources like rice straw, plantain compost, wood ash with FYM, rice straw with lime, plantain compost with lime, wood ash-FYM combination with lime and lime alone, all treated with potassic fertilizer. The details of the methods adopted and materials used during the course of research are summarized below:

Experiment 1. Characterisation of rice straw and plantain compost

3.1 Decomposition dynamics of rice straw and characterization

3.1.1Collection and processing of rice straw

Rice straw was collected from chemmanur area after the harvest of mundakan rice field in the last week of December. The sample was air dried and cut into small fine pieces (1-2cm) for analysis.

3.1.2 Physico-chemical properties

Rice straw was analyzed for pH, electrical conductivity, organic carbon, available N, P, K, Ca, Mg, S and important micro nutrients like Fe, Mn, Cu and Zn before the decomposition experiment and analyzed as given below:

Table1. Physico- chemical properties of rice straw

Characteristic	Method		Reference
	Extraction	Estimation	
pH	1:2.5 Sample Water suspension	Potentiometry	Jackson, 1958
Electrical conductivity		Conductometry	
Organic carbon	Wet digestion		Walkley and Black, 1934
Nitrogen	0.1N H_2SO_4	Modified Kjeldahl method	Jackson, 1973
Phosphorous	Nitric acid – perchloric acid (9:4) Di-acid digestion	Spectrophotometry	Bhargava and Raghupathi, 1984
Potassium		Flame photometry	
Calcium		Atomic Absorption Spectrophotometer (AAS)	
Magnesium			
Sulphur	Di-acid extract with 0.15% $BaCl_2$	Spectrophotometry	Massoumi and Cornfield, 1963
Micronutrients (Fe, Mn, Zn, and Cu)	Di-acid digestion	ICP OES (Model: Optima 8X00 series)	Sims and Johnson, 1991

3.1.3.Study of decomposition dynamics and potassium release rate of rice straw

Bulk soil samples (0-15cm) were collected from Instructional Farm, Vellanikara during December at three different locations. Three polythene boxes of size 25cm×15cm×10 cm were taken and 3 kg of these collected soil samples were packed in each of these boxes. Water was added (about 600 ml in each boxes) in order to maintain the field capacity of soil. Ten grams of dried pieces of straw were tied in a nylon bag of size 10cm×5cm and packed in each box. A total of 5 bags were placed and the tray was just covered with a plastic lid to avoid external disturbances during incubation. Water was sprayed in each boxes to prevent complete drying of soil. Nylon bags were removed from the boxes at different intervals viz. 7, 14, 30, 60 and 90 days after incubation. On each sampling date, one nylon bag was randomly removed from each box and mud particles were removed that were adhered to the bag. The residue of the rice straw was then dried at 40°c for 24 hours until reaching a constant weight. Fresh weight and dry weight of rice straw bags, before and after decomposition were recorded to determine the decomposition amount which is calculated as per formula (Li *et al.,* 2014):

Decomposition amount (g)

= (dry matter at 0^{th} day – remaining dry matter at n^{th} day) where n is the day of incubation

Decomposition rate (%) = (decomposition amount / dry matter at 0 day) ×100

The potassium release rate from each bag was also calculated at respective intervals using flame photometer. The plant sample was oven dried at 40°C for 24hrs to remove the moisture and digested with diacid mixture (HNO_3: HCl at 9:4 ratio) till thesolution becomes clear and is determined using flame photometer and potassium release rate is calculated as:

K release amount (mg) = K amount at 0^{th} day – K remaining at n^{th} day, where n is the day of incubation

K release rate (%) = (K release amount / K amount at 0^{th} day) ×100

Plate 1. Decomposition dynamics of rice straw

1. Collection of soil samples from Agronomy Instructional Farm, COA,Vellanikkara

2. Sieved soils (3 kg) packed in polythene boxes

3. Determination of field capacity

4. Water added to soil to maintain field capacity

5. Nylon bags containing rice straw to determine decomposition at different intervals

6. Decomposition study of rice straw

3.1.2. Preparation of plantain compost and its characterization

Plantain compost of *banana cv. nendran* was prepared in ex-situ condition using vermi technology at vermicompost unit of Banana Research Station, Kannara, Kerala.

3.1.2.1. Materials used:

The raw materials used were coconut husk, cow dung slurry, psuedostem cuttings, earthworm species *Eudrillus eugeniae*

3.1.2.2. Preparation

Vermicomposting of plantain compost was started in the second week of August. Three cylindrical tanks of height 66.5 cm and diameter 92cm were used. Initially the psuedostems of *banana cv. nendran* was cut into small pieces (1-5cm) using machine cutter after their harvest and it was spread under shade for 2 weeks to drain the water completely. Then on to the cylindrical tank, coconut husks were spread as first layer upto a height of 10-15cm, followed by cow dung and above it psuedostem was spread upto 15-20 cm. These layers were repeated once again and above the second layer of psuedostem, cow dung slurry was sprayed as an inoculant for microorganisms to grow and kept open for two weeks. After two-threeweeks' earthworms (*Eudrillus eugeneae)* 100 - 150 numbers were added in each tank. This is the most important step of vermicomposting in which these earthworms will turn over the entire materials and helps in complete decomposition. The tanks were then covered with jute bag. After every two weeks, mixing was done to bring the lower layer materials to top and also help to increase the rate of aerobic decomposition. Total of five turnings were done after every two weeks. Vermi wash was also collected from the small pipe located at the bottom of the tank. Each tank of volume 441.8 cm^3, had a capacity to carry 100 kg of raw materials. But after the complete processing, the ultimate product was about 30 kg from each tank. It took almost 1.5 months for the complete process. The vermicompost was taken out sieved and packed.

3.1.2.3. Physico- chemical properties

Initial characteristics of plantain compost viz, pH, EC, available N, P, K, Ca, Mg, S and important micro nutrients were analyzed in the same methods adopted in the rice straw mentioned in table 1.

Plate 2. Preparation of plantain compost

1. Cuttings of psuedostem spread to drain water

2. Coconut husk placed as first layer in the tank

3. Cow dung placed as second layer

4. Psuedostem cuttings as third layer

5. Final layer of psuedostems on the top of the tank

6. Final spread of cow dung on top of tank

7. Collection of earth worm after 2 weeks for composting

8. Earth worm species*Eudrilus eugeniae*

9. Spraying of cow dung slurry as inoculum

10. Turning of the materials using rake at regular intervals

11. Final form of compost

EXPERIMENT 2. POTASSIUM SORPTION STUDY

3.2.1Rice straw

From the decomposition study (experiment 1), 1g of each decomposed rice straw at respective intervals were taken into centrifuge tube along with various concentrations of KCl (0mg K/20ml, 7.5mg K/20ml, 15mg K/20ml, 30mg K/20ml, 45mg K/20ml, 60mg K/20ml) and were shaken for 4 hours and filtered out and the K concentrations were obtained from flame photometer. Then K adsorption on crop residue and K removing rates from solution were determined from each bag after different intervals of decomposition using standard formula (Li *et al.,* 2014):

$$Q = (C_o - C_t) \times V/m$$

$$R = (C_o - C_t) / C_o \times 100$$

Where, Q = K adsorption (mg g^{-1})

R= K removal rate from solution (adsorption rate) in (%)

C_o = Initial K concentration (mg/ml)

C_t= Equilibrium K concentration (mg/ml)

V= Volume of solution (ml)

m= Mass of the sample taken (g)

Concentrations of KCl taken were:

K concentrations (mg/20ml)	**KCl taken (mg/20ml)**
0	0
7.5	12.75
15	25.5
30	51
45	76.5
60	102

3.2.2 Plantain compost

The same K sorption study was conducted in the prepared compost at the same concentrations of KCl that were taken in the rice straw (0mg K/20ml, 7.5mg K/20ml, 15mg K/20ml, 30mg K/20ml, 45mg K/20ml, 60mg K/20ml) and its K sorption rate and K removing rate were also determined using the same formula. Three replications were carried out.

EXPERIMENT 3. INCUBATION STUDY

Incubation study was conducted in polythene boxes of sixe 25×15×10 cm containing 3 kg sieved air dried soil in each boxes along with crop residues or other K rich materials under different treatments. Potassium were applied at the rate of 1 g K per box in the form of Murate of Potash (MOP) in all boxes. Samples were drawn at regular intervals viz, 15, 30, 60 and 60 days after incubation and different forms of K such as exchangeable K, non-exchangeable K, water soluble K and total K were estimated using standard methods. Change in pH was also determined during these sampling intervals.

3.3.1 Collection of soil samples

Soil samples were collected from Instruction Farm, COA, Vellanikkara from F-block. Samples were taken from 27 locations randomly. Debris were removed from surfaces. Then V shape cuttings were made using spade up to a depth of 15 cm with 1.5 cm thickness from surface. Then the soil samples were air dried and sieved through 2 mm sieves and were packed in each boxes with 3 kg each.

3.3.2 Analysis of pre and post incubated physico-chemical properties of soils

Pre and post incubated characteristics of soils viz, pH, EC, available N, P, K, Ca, Mg, S and important micro nutrients were analysed.

1. Analysis of the incubation study

2. Collection of the soil samples for analysis during different intervals

Table 2. Treatment details of incubation experiment

Treatment No.	Treatments taken	Notations used
T_1	Rice straw (35g /box) + MOP (1g K/box)	RS + K
T_2	Plantain compost (35g/box) + MOP (1g/box)	PC +K
T_3	Wood ash with FYM (1:5) (35g/box) + MOP (1g/box)	WA: FYM +K
T_4	Rice straw (35g/box) + lime (0.8g/box) + MOP (1g/box)	RS+L+K
T_5	Plantain compost (35g/box) + lime (0.8g/box) + MOP (1g/box)	PC+L+K
T_6	Wood ash with FYM (35g/box) + lime (0.8g/box) + MOP (1g/box)	WA:FYM+L+K
T_7	Lime (0.8g/box) + MOP (1g/box)	L+K
T_8	MOP (1g/box)	K
T_9	Absolute control	Control

Table 3. Physico - chemical properties of soil

Characteristic	Method		Reference
	Extraction	Estimation	
pH	1:2.5 soil water suspension	Potentiometry	Jackson, 1958
Electrical conductivity		Conductometry	
Organic carbon	Wet digestion		Walkley and Black, 1934
Available N	Alkaline permanganometry		Subbiah and Asija, 1956
Available P	Bray No. 1	Spectrophotometry	Bray and Kurtz, 1945
Available K	1 N NH_4OAc	Flame photometry	Jackson, 1958
Available Ca		Atomic Absorption Spectrophotometer	
Available Mg			
Available S	0.15% $CaCl_2$	Spectrophotometry	Chesnin and Yein, 1951
Available micronutrients (Fe, Mn, Zn, and Cu)	0.1 N HCl	Atomic Absorption Spectrophotometer	Sims and Johnson, 1991

3.3.3Analysis of different forms of potassium

Different forms of potassium such as exchangeable K, non-exchangeable K, water soluble K and total K were determined at 0, 15, 30, 60 and 90 days after incubation. The methods adopted for their analysis is depicted below in table.

Table 4. Procedure for analysis of different forms of potassium in soil

Characteristic	Method		Reference
	Extraction	Estimation	
Available K	1 N NH_4OAc	Flame photometry	Hanway and Heidel, 1952
Water soluble K	1:5 soil water suspension	Flame photometry	Kanwar and Grewal, 1996
Exchangeable K	Difference between available K and water soluble K		Hanway and Heidel, 1952
Totak K	Digestion with perchloric – nitric acid	Flame photometry	Hesse, 1971 Jackson. 1973
Non- exchangeable K	Difference between nitric acid extracted K(total K) and ammonium acetate extracted K(available K)		Wood and De Turk, 1940

STATISTICAL ANALYSIS

Data on different forms of K of the incubated soils were statistically analyzed using CRD design with three replications in WASP 2.0 software and comparison between treatments were done at different intervals.

Results

4. RESULTS

The results of the study on "Utilisation of potassium rich crop residues for retention of potassium in lateritic soil" conducted in the PG laboratory of the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellanikkara during the period 2020-21 are furnished in this section.

EXPERIMENT 1.

CHARACTERISATION OF RICE STRAW AND PLANTAIN COMPOST

The physico-chemical properties of rice straw and prepared plantain compost was characterized before initiation of the experiment.

4.1 DECOMPOSITION DYNAMICS OF RICE STRAW AND POTASSIUM RELEASE

An incubation study was conducted in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellanikkara, 2020-21, to determine the decomposition dynamics of rice straw and its potassium release at different stages of decomposition viz., 7, 14, 30, 60 and 90 days after incubation. Physico- chemical properties of rice straw used for the study were estimated prior to the decomposition study.

4.1.1 Physico- chemical properties of rice straw

The important physico- chemical properties of rice straw viz., pH, EC, total carbon, major nutrients N, P, K, secondary nutrients Ca, Mg, S and important micro nutrients Fe, Cu, Zn, Mn were estimated. Moisture content in the rice straw was also determined. The data are presented in table 4.1.

Analytical results showed that rice straw had slightly acidic pH of 5.8 with electrical conductivity of 0.019 dSm^{-1} and moisture content of 10.00 per cent. Rice straw registered higher potassium content (1.53%) than nitrogen (0.76 %) and phosphorous (0.053%). The calcium content (0.32 %) was higher compared to magnesium (0.107 %) and sulphur (0.05 %). It also registered higher iron (0.33%) and manganese (0.76%) compared to zinc (0.036%) and copper (0.0028%).

Table 4.1 Physico-chemical properties of rice straw

Properties	**Value**
pH	5.8
Electrical conductivity (dS m^{-1})	0.019
Moisture content (%)	10.00
Total carbon (%)	53.20
Nitrogen (%)	0.76
Phosphorous (%)	0.053
Potassium (%)	1.53
Calcium (%)	0.32
Magnesium (%)	0.107
Sulphur (%)	0.05
Iron (%)	0.23
Copper (%)	0.003
Zinc (%)	0.036
Manganese (%)	0.24

4.1.2 Decomposition rate of rice straw

From the incubation experiment, amount and rate of decomposition of rice straw was determined at different intervals viz., 7, 14, 30, 60 and 90 days after incubation. A total of five nylon bags, each containing 1 g rice straw in three boxes were analysed at these intervals.

Decomposition amount (g)

= Dry matter at 0^{th} day – remaining dry matter at n days,

where n is the number of incubation days

Decomposition rate (%)

= Decomposition amount / dry matter at 0^{th} day ×100

The results showed (table 4.2) an increasing trend in decomposition of rice straw from each bag over the different time intervals selected for the study. Maximum decomposition was attained in 90 days of incubation (51.90 %), followed by 60 days (40.26 %), 30 days (34.63 %), 14 days (21.26 %) and 7 days (17.80 %) of incubation. The increase in percentage of decomposition was higher between 14 to 30 days followed by 60 to 90 days of decomposition.

Table 4.2.Decomposition of rice straw at different periods of incubation

Incubation intervals (days)	Decomposed amount (g)	Decomposition rate (%)
7	1.78	17.80
14	2.12	21.26
30	3.46	34.63
60	4.02	40.26
90	5.19	51.9

4.1.3 EXTENT OF POTASSIUM RELEASE FROM RICE

The extent of potassium release from each bag was also determined at different time intervals of the study which was calculated in the following manner.

K release amount (mg) = K amount at 0th day – K remaining at n day

K release (%) = K release amount / K amount at 0th day × 100

From the results indicated in table 4.3, an increasing value of K release was observed over the different time intervals. Among the different incubation intervals, maximum quantity of K release was observed at 90 days (84.28 %) after incubation of rice straw. The rate of release of K from the straw at 7 days was only 47.71 percentage. At 14, 30 and 60 days after incubation the rate of release of K from the straw were 64.09%, 69.67 and 78.47% respectively which showed an increased trend in the value. Among these incubation periods, the highest increase in rate of K release was noticed from 7 to 14 days of decomposition.

Table 4.3 Magnitude of potassium release from rice straw at different incubation intervals

Incubation intervals (days)	K release amount (mg /g)	K release rate (%)
7	7.30	47.71
14	9.80	64.09
30	10.66	69.67
60	12.00	78.47
90	12.89	84.28

4.1.4. PREPARATION OF PLANTAIN COMPOST AND ITS CHARACTERISATION

Vermi compost was prepared using plantain residues which mainly consists of its psuedostem collected at Banana Research Station, Kannara. The properties of the plantain compost prepared by vermi technology were determined before starting the adsorption study and the data are presented in table 4.4.

Plantain compost had an alkaline pH of 9.3 with electrical conductivity of 0.064 dSm^{-1}. The moisture content was about 9.4 per cent. Comparing the values of primary nutrients, it was rich in K (1.33%) followed by P (1.04%) and N (0.30%). Among the secondary nutrients, Ca (0.50%) content was higher than Mg (0.23%) and S (0.08%). On comparing the micronutrients viz, Fe, Mn, Zn and Cu, it was found that the nutrient content followed the order Fe (0.36%)> Zn (0.17%) >Mn (0.10%) >Cu (0.04%).

Table 4.4. Physico-chemical properties of plantain compost

Properties	**value**
pH	9.3
Electrical conductivity(dS m^{-1})	0.063
Moisture content (%)	9.40
Total carbon (%)	28.24
Nitrogen (%)	0.30
Phosphorous (%)	1.04
Potassium (%)	1.33
Calcium (%)	0.50
Magnesium (%)	0.23
Sulphur (%)	0.08
Iron (%)	0.36
Copper (%)	0.04
Zinc (%)	0.17
Manganese (%)	0.10

EXPERIMENT NO. 2

4.2. SORPTION STUDY

Potassium adsorption study was conducted in rice straw at different intervals of decomposition using various levels of KCl viz, 0.00 mg, 7.5mg, 15.0mg, 30.0 mg, 45.0 mg and 60.0 mg K/20ml. Along with it, prepared plantain compost was also taken to determine the potassium adsorption at different levels of KCl in the same way as done in rice straw.

4.2.1 POTASSIUM ADSORPTION ON RICE STRAW

From the decomposition study conducted with rice straw, the extent of K adsorption and K release was estimated at different incubation intervals viz., 7, 14, 30, 60 and 90 days after incubation using various levels of KCl such as, 0.00 mg, 7.5mg, 15.0mg, 30.0 mg, 45.0 mg and 60.0 mg K/20ml respectively and were shaken for 4 hrs. The magnitude of K adsorption was calculated as:

K adsorption on straw Q (mg g^{-1})

$$Q = C_o - C_t \times V/m$$

Where, C_o is the initial K concentration

C_t is the final equilibrium concentration obtained

V is the volume of KCl taken (20 ml)

m is the mass of rice straw taken at different decomposition intervals (1g)

K adsorption rate(K removal from solution) (%)

$$R\ (\%) = C_o - C_t / C_o \times 100$$

The magnitude of K adsorption on rice straw and K removal from solution by straw under different stages of decomposition are presented in table 4.5, 4.6, 4.7, 4.8 and 4.9 respectively.

From the results, it was observed that, the adsorption of potassium from KCl solution has been increased as the decomposition interval increases. There were 6 different levels of KCl solution used to determine the adsorption in rice straw.

After 7 days of decomposition, K removal rate from the solution was zero at 0.00 mg K/20 ml solution. The magnitude of K adsorption increased as the concentration of KCl increased. The value of K adsorption at 7.50, 15.00, 30.00, 45.00 and 60.00 mg K/20ml solution followed the order, 0.58 mg g^{-1}< 0.67 mg g^{-1}< 1.30 mg g^{-1}< 1.72 mg g^{-1}< 2.68 mg g^{-1}. The amount of K that was removed from the solution has got completely adsorbed on the straw surface.

After 14 days of decomposition, the magnitude of K adsorption had increased compared to initial decomposition period. The value of adsorption followed the order as -5.54 mg g^{-1}< 0.70 mg g^{-1}< 0.99 mg g^{-1}< 1.45 mg g^{-1}< 2.47 mg g^{-1}< 4.26 mg g^{-1} at 0.00, 7.50, 15.00, 30.00, 45.00 and 60.00 mg K/20ml solution.

After 30 days of decomposition period, K adsorption on rice straw also showed a higher vale compared to 14 days. Similarly, the higher value of 7.73 mg g^{-1} was obtained at 60.00 mg K/20ml followed by 45.00, 30.00 15.00 and 7.60 mg K/20ml solution with values of 4.48 mg g^{-1}, 1.68 mg g^{-1} and 0.84 mg g^{-1} respectively. There also observed a negative adsorption at 0.00mg K/20 ml with a negative value of -3.85 mg g^{-1}.

After 60 days of decomposition period, the value also showed an increment in the adsorption with values of 1.00 mg g^{-1}< 1.41 mg g^{-1}< 4.80 mg g^{-1}< 8.20 mg g^{-1}< 12.51 mg g^{-1} respectively at 7.50, 15.00, 30.00, 45.00 and 60.00 mg K/20ml solution. The value at 0.00 mg K/20ml showed a negative value of -2.40 mg g^{-1} which showed a lower value of desorption compared to 30 days after decomposition.

After 90 days of decomposition period, a higher value of adsorption on straw was observed compared to other decomposition intervals. The values at 7.50, 15.00, 30.00, 45.00 and 60.00 mg K/20ml solution was followed as, 1.02 mg g^{-1}< 2.35 mg g^{-}

^{1}< 6.76 mg g^{-1}< 10.50 mg g^{-1}< 16.08 mg g^{-1} respectively. The value of adsorption again noticed a negative value at 0.00 mg K/20ml with a value of -2.35 mg g^{-1} which was comparatively lower negative value compared to other decomposition intervals.

Table 4.5 Potassium adsorption study on rice straw after 7 days of decomposition

Levels of KCl solution (mg K/20ml)	Quantity of K adsorbed on rice straw (mg g^{-1})	K adsorption rate (%)
0	-6.36	0
7.5	0.58	7.73
15	0.67	4.46
30	1.30	4.33
45	1.72	3.82
60	2.68	4.46

Table 4.6. Potassium adsorption study on rice straw after 14 days of decomposition

Levels of KCl solution (mg K/20ml)	Quantity of K adsorbed on rice straw (mg g^{-1})	K adsorption rate (%)
0	-5.54	0
7.5	0.70	9.33
15	0.99	6.60
30	1.05	3.51
45	2.47	5.48
60	4.26	7.10

Table 4.7. Potassium adsorption study on rice straw after 30 days of decomposition

Levels of KCl solution (mg K/20ml)	Quantity of K adsorption on rice straw (mg g^{-1})	K adsorption rate (%)
0	-3.85	0
7.5	0.77	10.20
15	0.84	5.60
30	1.68	5.65
45	4.48	9.87
60	7.73	12.87

Table 4.8. Potassium adsorption study on rice straw after 60 days of decomposition

Levels of KCl solution (mg K/20ml)	Quantity of K adsorbed on rice straw (mg g^{-1})	K adsorption rate (%)
0	-2.40	0
7.5	1.00	13.33
15	1.41	9.39
30	4.80	16.00
45	8.20	18.22
60	12.51	20.85

Table 4.9. Potassium adsorption study on rice straw after 90 days of decomposition

Levels of KCl solution (mg K/20ml)	Magnitude of K adsorption on rice straw (mg g^{-1})	K adsorption rate (%)
0	-2.35	0
7.5	1.02	13.60
15	2.33	15.53
30	6.76	22.55
45	10.50	23.33
60	16.08	26.36

Table 4.10 Potassium adsorption study on plantain compost

Level of KCl solution (mgK/20ml)	Quantity of K adsorbed on plantain compost (mg g^{-1})	K adsorption rate (%)
0	-9.84	0
7.5	0.12	1.60
15	1.57	11.06
30	12.38	41.29
45	24.89	55.32
60	37.29	62.14

4.2.2. POTASSIUM SORPTION STUDY ON PLANTAIN COMPOST

Similarly, potassium sorption study was conducted in the prepared plantain compost using different levels of KCl in the same way as done in the rice straw. The results obtained are given in table 4.10.

The above data shows the K adsorption and K removal rate from already prepared plantain compost. It was also observed that there was an increment in the value of adsorption as the level of KCl solution increased. The value at 7.50, 15.00, 30.00 45.00 and 60.00 mgK/20ml solution followed as, 0.12 mg g^{-1}< 1.57 mg g^{-1}< 12.38 mg g^{-1}< 24.89 mg g^{-1}< 37.29 mg g^{-1} respectively. The value of adsorption showed a negative value of -9.84 mg g^{-1} at 0.00 mg K/20 ml solution.

Table 4.11 Parameters of adsorption curve of rice straw and plantain compost

Days of decomposition	Linear equation	R^2	Slope
7 days	y = 0.8196x + 156.47	$R^2 = 0.96$	0.81
14 days	y = 1.3777x - 145.3	$R^2 = 0.86$	1.377
30 days	y = 3.0241x - 1194.2	$R^2 = 0.88$	3.02
60 days	y = 5.7317x - 1845.7	$R^2 = 0.97$	5.73
90 days	y = 7.9593x - 2276.9	$R^2 = 0.98$	7.95
Plantain compost	y = 46.722x - 22446	$R^2 = 0.81$	46.72

Table 4.12 Parameters of Freundlich adsorption isotherm of rice straw and plantain compost

Days of decomposition	linear equation	R^2	1/n	Kf
7	y = 0.7227x + 0.8558	0.93	0.72	7.17
14	y = 0.7754x + 0.8026	0.79	0.77	6.34
30	y = 1.1249x - 0.1163	0.84	1.12	0.76
60	y = 1.3364x - 0.4643	0.95	1.33	0.34
90	y = 1.4517x - 0.6556	0.99	1.45	0.22
Plantain compost	y = 3.2261x - 5.4197	0.82	3.22	3.80452E-06

4.3. INCUBATION STUDY

The third experiment was an incubation study conducted with different K rich sources along with Muriate of Potash (MOP). Lime was also incorporated as per treatments. Totally there were nine treatments. Physico-chemical properties of soil such as pH, EC, organic carbon, available N, P, Ca, Mg, S and important micro nutrients such as Fe, Cu, Zn and Mn were also analyzed. The different forms of K such as total K, non- exchangeable K, available K, exchangeable K and water soluble K were also analyzed at different intervals such as 0, 15, 30, 60 and 90 days after incubation. The changes in pH during these intervals were also recorded and the data are presented in table. 4.9.

4.3.1. Soil pH

Changes in pH were monitored during respective intervals and are presented in table 4.13. The treatment consisted of wood ash with FYM, lime and MOP (T6) was having higher value of pH during 0, 15, 30, 60 and 90 days of incubation with values as 6.17, 6.19, 6.18, 6.20 and 6.17 respectively. After T6, the next higher pH was reported in the treatment consisting of wood ash with FYM and MOP (T3), followed by T5 treatment which included plantain compost, lime and MOP. The trend during 0 day and 15 days after incubation followed the same order as, T6> T3> T5> T7> T4>T2>T9>T8>T1.

After 30 days of incubation, a slightly higher pH was observed in the treatment with wood ash with FYM, lime and MOP (T6) and wood ash with FYM and MOP (T3) which were on par with each other. The plantain compost with lime and MOP (T5) along with lime alone treatment (T7) reported the second highest value.

The trend followed T1<T8<T2=T9<T4<T7=T5<T3=T6. The trend in the value during 60 days after incubation followed as, T6>T3>T5>T7>T2>T9>T8>T4>T1 with highest value again in wood ash with FYM, lime and MOP treatment.

After 90 days of incubation, the value in pH under different treatments were followed as, T6>T3>T5>T7>T2>T9>T8>T4>T1 with the highest value in the treatment T6 containing wood ash-FYM with lime and MOP (6.17) that was again followed by wood ash-FYM with MOP (T3) and plantain compost with lime and MOP (T5) with values of 6.16 and 5.49 respectively. The treatments were found significantly different at all incubation intervals.

Table 4.13 pH of the soil under different treatments during the incubation period

Treatments	Incubation period (days)				
	0	15	30	60	90
T1: RS (35g/box) +MOP ($1gK_2O$ /box)	4.84^{i}	4.90^{i}	4.92^{f}	5.22^{f}	5.09^{g}
T2: PC (35g/box) + MOP ($1gK_2O$ /box)	5.25^{f}	5.29^{f}	5.28^{d}	5.43^{e}	5.31^{d}
T3: WA: FYM (35g/box) +MOP ($1gK_2O$ /box)	6.10^{b}	6.11^{b}	6.17^{a}	6.19^{a}	6.16^{a}
T4: RS (35g/box) + L (0.8g/box) +MO P ($1gK_2O$ /box)	5.57^{e}	5.58^{e}	5.58^{c}	5.59^{d}	5.17^{g}
T5: PC (35g/box) + L (0.8g/box) + MOP (1g K_2O/box)	5.77^{c}	5.79^{c}	5.77^{b}	5.73^{b}	5.49^{b}
T6: WA: FYM (35g/box) + L (0.8g/box) +MOP ($1gK_2O$ /box)	6.17^{a}	6.19^{a}	6.18^{a}	6.20^{a}	6.17^{a}
T7: L (0.8g/box)+MOP ($1gK_2O$ /box)	5.70^{d}	5.76^{d}	5.72^{b}	5.67^{c}	5.40^{c}
T8: ($1gK_2O$ /box)	5.20^{h}	5.21^{h}	5.19^{e}	5.20^{f}	5.20^{f}
T9: Control	5.22^{g}	5.23^{g}	5.23^{d}	5.23^{g}	5.23^{f}
CD $_{(0.05)}$	0.021*	0.017*	0.100*	0.003*	0.007*

*found significant at 5% level of significance

4.3.2 Electrical conductivity

Electrical conductivity of soil samples was estimated at 0 and 90 days after incubation and recorded in table 4.14. All the treatments registered very low electrical conductivity. During 0 and 90 days after incubation, treatment with wood ash with FYM, lime and MOP(T6) was having slight higher value (0.008 dSm^{-1}) compared to other treatments. The trend during 0 and 90 days after incubation followed as, T6 >T7=T5=T4=T3=T2>T8>T1>T9.

Table 4.14. Electrical conductivity (dSm^{-1}) of the soil samples at 0 and 90 days after incubation

Treatments	At 0 days	At 90 days
T1 : Rice straw (35g/box) + MOP (1g K_2O/box)	0.007^{bc}	0.007^{bc}
T2 : Plantain compost (35g/box) + MOP (1g K_2O/box)	0.006^{ab}	0.006^{ab}
T3: Wood ash with FYM (35g/box) + MOP (1g K_2O/box)	0.007^{ab}	0.007^{ab}
T4 : Rice straw (35g/box) + Lime (0.8g/box) + MOP (1g K_2O/box)	0.008^{ab}	0.008^{ab}
T5: Plantain compost (35g/box) + Lime (0.8g/box) + MOP (1g K_2O/box)	0.007^{ab}	0.007^{ab}
T6: Wood ash with FYM (35g/box) + Lime (0.8g/box) + MOP (1g K_2O/box)	0.008^{a}	0.008^{a}
T7: Lime (0.8g/box)+ MOP (1g K_2O/box)	0.005ab	0.005^{ab}
T8 : MOP (1g K_2O/box)	0.005abc	0.005^{abc}
T9 : control	0.001^{c}	0.001^{c}
CD(0.05)	0.003*	0.003*

*found significant at 5% level of significance

4.3.2. Soil organic carbon

Organic carbon content of soil samples taken at 0 and 90 days of incubation was analyzed and the data are given in the table 4.15. At 0 day of incubation, organic carbon content was higher in the treatment with rice straw and MOP (T1) with value 1.76 per cent followed by straw with lime and MOP treatment (T4) with value of 1.63 per cent. The trend followed as T1 (1.76 %) >T4 (1.63 %) >T2 (1.61 %) >T5 (1.58 %) >T3 (1.46 %) >T6 (1.35 %) >T7 (1.30 %) >T8 (1.21 %) >T9 (1.17 %).

After 90 days of incubation, organic carbon content in all treatments decreased but the value was again higher in treatment T1 (rice straw with MOP) with value 1.61 per cent which was followed by plantain compost with MOP treatment (T2) with a value of 1.53 per cent. The order of the treatments was T1 (1.61 %) >T2 (1.53 %) >T4 (1.50 %) >T5 (1.48 %) >T3 (1.36 %) >T8 (1.28 %) >T7 (1.25 %) =T6 (1.25 %) >T9 (1.16 %). The treatments were found significantly different both at 0 and 90 days of incubation.

Table 4.15. Soil organic carbon (%) content in the soil samples at 0 and 90 days after incubation

Treatments	Incubation period (days)	
	0 days	90 days
T1 : Rice straw (35g/box) + MOP (1g K_2O/box)	1.76[a]	1.61[a]
T2 : Plantain compost (35g/box) + MOP (1g K_2O /box)	1.61[c]	1.53[b]
T3 : Wood ash with FYM (35g/box) + MOP (1g K_2O /box)	1.46[e]	1.36[e]
T4 : Rice straw (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	1.63[b]	1.50[c]
T5 : Plantain compost (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	1.58[d]	1.48[d]
T6 : Wood ash with FYM (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	1.35[f]	1.25[f]
T7: Lime (0.8g/box)+ MOP (1g K_2O /box)	1.30[g]	1.25[f]
T8 : MOP (1g K_2O /box)	1.21[h]	1.20[h]
T9 : control	1.17[i]	1.16[h]
CD(0.05)	0.004*	0.004*

*found significant at 5% level of significance

4.3.3. Available nitrogen

The available nitrogen content in soil samples were estimated at 0 and 90 days after incubation (Table 4.16). It was found that a decreasing trend was observed in nitrogen content of soil from 0 to 90 days.

At 0 day of incubation, treatment T4 (Rice straw with lime and MOP) was having higher contribution to available N in soil with value of 156.80 mg kg^{-1} followed by the treatments that included rice straw with MOP (T1) and plantain compost with lime and MOP (T5) which were on par with each other.

But after 90 days of incubation, average N content in all the treatments decreased but the rate of release was also lower in rice straw with lime and MOP (T4) treatment with value of 151.19mg kg^{-1}which was followed by plantain compost with lime and MOP (T5) with value of 134.39 mg kg^{-1}. Those treatments consisted of rice straw with MOP (T1) and plantain compost with MOP (T2) were on par with each other with values 132.80 mg kg^{-1} and 132.60 mg kg^{-1} respectively. Therefore, application of organic sources and MOP along with lime reported higher nitrogen content in soil.

During 0 day of incubation, trend in the value followed as, T4 (156.80 mg kg^{-1}) > T5 (140.00 mg kg^{-1}) =T1 (140.00 mg kg^{-1}) > T2 (139.75 mg kg^{-1})> T6 (128.75 mg kg^{-1}) > T3 (123.12 mg kg^{-1}) > T7 (117.59 mg kg^{-1}) > T8 (112.00 mg kg^{-1}) > T9 (108.00 mg kg^{-1}). While after 90 days of incubation the trend in the values followed as, T4 (151.19 mg kg^{-1}) >T5 (134.39 mg kg^{-1}) > T2 (132.60 mg kg^{-1}) =T1 (132.80mg kg^{-1}) >T6 (123.19 mg kg^{-1}) >T3 (1117.59 mg kg^{-1}) >T7 (100.80 mg kg^{-1}) > T8 (106.39 mg kg^{-1}) >T9 (107.50 mg kg^{-1}). The treatments were found significantly different at both intervals.

Table 4.16 Available nitrogen (mg kg^{-1}) content in the soil samples at 0 and 90 days after incubation

Treatments	At 0 days	At 90 days
T1 : Rice straw (35g/box) + MOP (1g K_2O /box)	140.00^{b}	132.80^{c}
T2 : Plantain compost (35g/box) + MOP (1g K_2O /box)	139.75^{c}	134.64^{b}
T3 : Wood ash with FYM (35g/box) + MOP (1g K_2O /box)	123.12^{e}	117.59^{e}
T4 : Rice straw (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	156.80^{a}	151.19^{a}
T5 : Plantain compost (35g/box) + Lime (0.8g/box) + MOP (1g/box)	140.00^{b}	134.39^{b}
T6 : Wood ash with FYM (35g/box) + Lime (0.8g/box) + MOP (1g/box)	128.75^{d}	123.19^{d}
T7: Lime (0.8g/box)+ MOP (1g/box)	117.59^{f}	107.80f
T8 : MOP (1g K_2O/box)	110.00^{g}	106.39^{g}
T9 : control	108.00^{h}	106.50^{h}
CD (0.05)	0.001*	0.001*

*found significant at 5% level of significance

4.3.4. Available phosphorous

The available P content in soil samples were analyzed at 0 and 90 days after incubation and are presented in table 4.17. It showed a decreasing trend in available P in all treatments from 0 to 90 days of incubation.

During 0 day of incubation, treatment consisted of wood ash with FYM and MOP reported highest P content (38.30 mg kg^{-1}) which was followed by wood ash with FYM, lime and MOP (T6) with value of 30.04 mg kg^{-1}. The treatments followed as, T9 (10.05 mg kg^{-1}) < T8 (10.83 mg kg^{-1}) < T7 (12.70 mg kg^{-1}) < T4 (22.64 mg kg^{-1}) < T5 (23.09 mg kg^{-1}) < T1 (25.85 mg kg^{-1}) < T2 (26.46 mg kg^{-1}) < T6 (30.04 mg kg^{-1}) < T3 (38.30 mg kg^{-1}).

After 90 days of incubation, available P content has decreased but comparing to all other treatments available P content was again maximum in T3 treatment with value (36.45 mg kg^{-1}), which was again followed by wood ash with FYM, lime and MOP treatment (T6), plantain compost with MOP (T2) and rice straw with MOP (T1) with values of 27.16mg kg^{-1}, 24.04 mg kg^{-1} and 22.19 mg kg^{-1} respectively. The trend followed the same order as, T9 (10.03 mg kg^{-1}) < T8 (10.21 mg kg^{-1}) < T7 (11.82 mg kg^{-1}) < T4 (20.74 mg kg^{-1}) < T5 (21.49 mg kg^{-1}) < T1 (22.19 mg kg^{-1}) < T2 (24.04 mg kg^{-1}) < T6 (27.16 mg kg^{-1}) < T3 (36.45mg kg^{-1}). The treatments were found significantly different at both the incubation intervals. So those treatments without lime application reported the higher P content compared to limed treatments (except for wood ash treated soil).

Table 4.17. Available phosphorous (mg kg^{-1}) content in the soil samples at 0 and 90 days after incubation

Treatments	At 0 days	At 90 days
T1 : Rice straw (35g/box) + MOP (1g K_2O/box)	25.85^{d}	22.19^{d}
T2 : Plantain compost (35g/box) + MOP (1g K_2O /box)	22.46^{c}	24.04^{c}
T3: Wood ash with FYM (35g/box) + MOP (1g K_2O /box)	38.30^{a}	36.45^{a}
T4 : Rice straw (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	22.64^{f}	20.74^{f}
T5: Plantain compost (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	23.09^{e}	21.49^{e}
T6: Wood ash with FYM (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	30.04^{b}	27.16^{b}
T7: Lime (0.8g/box)+ MOP (1g/ K_2O box)	12.70^{g}	11.82^{g}
T8 : MOP (1g K_2O /box)	10.83^{h}	10.21^{h}
T9 : control	10.05^{i}	9.18^{i}
CD (.0.05)	0.27*	0.29*

*found significant at 5% level of significance

4.3.5. Available calcium

The available Ca after application of different treatments in soil samples was analyzed at 0 and 90 days after incubation and given in table 4.18. Here, an increasing trend was observed in available Ca in all the treatments from 0 to 90 days of incubation (except for control treatment).

During 0 day of incubation, treatment consisted of Wood ash with FYM, lime and MOP (T6) reported highest available Ca content (493.33 mg kg^{-1}) which was followed by treatment with wood ash with FYM and lime (T3), plantain compost with lime and MOP (T5) and rice straw with lime and MOP (T4) with values of 467.00 mg kg^{-1}, 388.33 mg kg^{-1} and 378.50 mg kg^{-1}. After 90 days of incubation, available Ca content increased and again the highest value was obtained in T6 treatment (wood ash with FYM with lime and MOP) with value of 716.33 mg kg^{-1} which was again followed by wood ash with FYM and MOP (T3), plantain compost with lime and MOP (T5) and rice straw with lime and MOP (T4) with values of 660.16mg kg^{-1}, 631.83 mg kg^{-1} and 553.66 mg kg^{-1}. So those treatments with lime application reported the higher value of available Ca compared with non-limed treatments and among this wood ash treated soil reported the highest values.

. The trend in the value of treatments followed as, T6 (493.33 mg kg^{-1}) > T3 (467.00 mg kg^{-1}) > T5 (388.33 mg kg^{-1}) > T4 (378.50 mg kg^{-1}) > T7 (358.16 mg kg^{-1}) > T1 (205.16 mg kg^{-1}) > T8 (130.83 mg kg^{-1}) > T9 (128.66 mg kg^{-1}). While 90 days of incubation, the trend in the value followed as, T6 (716.33 mg kg^{-1}) > T3 (660.16 mg kg^{-1}) > T5 (631.83 mg kg^{-1}) > T4 (553.66 mg kg^{-1}) > T7 (542.66 mg kg^{-1}) > T2 (316.16 mg kg^{-1}) > T1 (310.16 mg kg^{-1}) > T8 (130.66 mg kg^{-1}) > T9 (125.00 mg kg^{-1}). The treatments were found significantly different at both the incubation intervals.

Table 4.18 Available calcium (mg kg^{-1}) content in the soil samples at 0 day and 90 days after incubation

Treatments	At 0 days	At 90 days
T1 : Rice straw (35g/box) + MOP (1g K_2O /box)	228.16[g]	310.16[g]
T2 : Plantain compost (35g/box) + MOP (1g K_2O /box)	268.50[f]	316.16[f]
T3 : Wood ash with FYM (35g/box) + MOP (1g K_2O /box)	467.00[b]	660.16[b]
T4 : Rice straw (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	378.50[d]	553.66[d]
T5 : Plantain compost (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	388.33[e]	631.83[c]
T6 : Wood ash with FYM (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	493.33[a]	716.33[a]
T7: Lime (0.8g/box)+ MOP (1g K_2O /box)	358.16[e]	542.66[e]
T8 : MOP (1g K_2O /box)	218.66[h]	215.65[h]
T9 : control	212.66[i]	210.00[i]
CD(0.05)	0.76*	0.55*

*found significant at 5% level of significance

4.3.6 Available magnesium

The available Mg content in soil samples after application of different treatments were analyzed at 0 and 90 days of incubation and presented in table 4.19. Here also, an increasing trend was observed in available Mg in all treatments from 0 to 90 days of incubation.

During 0 day of incubation, treatment consisted of wood ash with FYM, lime and MOP (T6) was having higher available Mg content (130.66 mg kg^{-1}) which was followed by wood ash with FYM and MOP (T3) with value of 130.00 mg kg^{-1} The trend in the values followed as, T6 (130.66 mg kg^{-1}) > T3 (130.00 mg kg^{-1}) > T5 (127.33 mg kg^{-1}) > T4 (126.66 mg kg^{-1}) > T2 (98.16 mg kg^{-1}) > T1 (76.16 mg kg^{-1}) > T7 (41.28mg kg^{-1}) > T8 (40.18mg kg^{-1}) > T9 (40.66 mg kg^{-1}). After 90 days of incubation, available Mg content has again increased in treatment T6 (woodash with FYM with lime and MOP) with a value of (160.66mg kg^{-1}) which was again followed by wood ash with FYM and MOP with value of 130.00 mg kg-1. The value among the treatments followed as, T6 (160.66 mg kg^{-1}) > T3 (155.33 mg kg^{-1}) > T5 (150.33 mg kg^{-1}) > T4 (146.00 mg kg^{-1}) > T2 (110.16 mg kg^{-1}) > T1 (106.16 mg kg^{-1}) > T7 (43.33mg kg^{-1}) > T8 (40.10 mg kg^{-1}) > T9 (39.83 mg kg^{-1}). The treatments were found significantly different at both incubation intervals.

Table 4.19. Available magnesium (mg kg^{-1}) content of soil samples with different treatments at 0 and 90 days after incubation

Treatments	At 0 days	At 90 days
T1 : Rice straw (35g/box) + MOP (1g K_2O /box)	76.16^{f}	106.16^{f}
T2 : Plantain compost (35g/box) + MOP (1g K_2O /box)	98.16^{e}	110.16^{e}
T3 : Wood ash with FYM (35g/box) + MOP (1g K_2O /box)	130.00^{b}	155.33^{b}
T4 : Rice straw (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	126.66^{d}	146.00^{d}
T5 : Plantain compost (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	127.33^{c}	150.33^{c}
T6 : Wood ash with FYM (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	130.66^{a}	160.66^{a}
T7: Lime (0.8g/box)+ MOP (1g K_2O /box)	41.28^{g}	43.33^{g}
T8 : MOP (1g K_2O /box)	40.18^{h}	40.10^{h}
T9 : control	40.66i	39.83^{i}
CD (0.05)	0.55*	0.62*

*found significant at 5% level of significance

4.3.7. Available sulphur

The available S content in soil samples after application of different treatments was analyzed at 0 and 90 days after incubation and presented in table 4.20. Here, a decreasing trend was observed in available S content in all treatments from 0 to 90 days of incubation.

During 0 day of incubation, treatment containing wood ash with FYM, lime and MOP reported the highest available S content (9.01 mg kg^{-1}) which was followed by wood ash with FYM and MOP (T3), plantain compost with lime and MOP (T5) and rice straw with lime and MOP (T4) with values of 8.08 mg kg^{-1}, 7.66 mg kg^{-1} and 7.15 mg kg^{-1} respectively.

After 90 days of incubation, available S content decreased in all treatments and here also treatment with wood ash with FYM, lime and MOP (T6) reported higher available S content with value of 7.77 mg kg^{-1}. The second and third higher value was also observed in wood ash with MOP (T3) and plantain compost with lime and MOP (T5) with values of 7.15 mg kg^{-1} and 6.21 mg kg^{-1}. The trend in the values during 0 day after incubation among the treatments followed the order T6 (9.01 mg kg^{-1}) > T3 (8.08 mg kg^{-1}) > T5 (7.66 mg kg^{-1}) > T4 (6.41 mg kg^{-1}) > T2 (6.62 mg kg^{-1}) >T1(4.86 mg kg^{-1}) > T7 (4.24 mg kg^{-1}) > T8 (4.18 mg kg^{-1}) > T9 (4.00 mg kg^{-1}) while after 90 days of incubation, the trend followed the same order as, T6 (7.77 mg kg^{-1}) > T3 (7.15 mg kg^{-1}) > T5 (6.21 mg kg^{-1}) > T4 (5.59 mg kg^{-1}) > T2 (5.28 mg kg^{-1}) > T1 (3.66 mg kg^{-1}) > T7 (2.79 mg kg^{-1}) > T8 (2.48 mg kg^{-1}) > T9 (2.30 mg kg^{-1}) respectively. The treatments were found significantly different at both the incubation intervals.

Table 4.20 Available sulphur (mg kg^{-1}) content of soil samples with different treatments at 0 and 90 days after incubation

Treatments	At 0 days	At 90 days
T1 : Rice straw (35g/box) + MOP (1g K_2O /box)	4.24^{g}	3.66^{f}
T2 : Plantain compost (35g/box) + MOP (1g K_2O /box)	6.62^{e}	5.28^{e}
T3: Wood ash with FYM (35g/box) + MOP (1g K_2O /box)	8.08^{b}	7.15^{b}
T4 : Rice straw (35g/box) + Lime (0.8g/box) + MOP (1g K_2O box)	7.15^{d}	5.59^{d}
T5: Plantain compost (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	7.66^{c}	6.21^{c}
T6 : Wood ash with FYM (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	9.01^{a}	7.77^{a}
T7: Lime (0.8g/box)+ MOP (1g K_2O /box)	4.24^{g}	2.79^{g}
T8 : MOP (1g K_2O /box)	4.18^{g}	2.48^{h}
T9 : control	4.00^{i}	2.30^{i}
CD (0.05)	0.23*	0.25*

*found significant at 5% level of significance

4.3.8 Available iron

The available Fe content in soil samples after application of different treatments was analyzed at 0 and 90 days after incubation and presented in table 4.21. Here, an increasing trend was observed in available Fe content in all treatments from 0 to 90 days of incubation except for control treatment.

During 0 day of incubation, treatment containing Plantain compost with lime and MOP reported the highest value of available Fe content with values of 14.27 mg kg^{-1} which was later followed by wood ash with FYM, lime and MOP (T6), rice straw with lime and MOP and plantain compost with MOP (T2) with values of 13.73 mg kg-1, 12.73 mg kg^{-1} and 12.00 mg kg^{-1} respectively. The treatments containing lime alone (T7) and lime with MOP (T8) showed similar value. The trend followed as, T5 (14.27 mg kg^{-1}) >T6 (13.72 mg kg^{-1})>T4 (12.73 mg kg^{-1})> T2 (12.00 mg kg^{-1}) >T3 (11.95 mg kg^{-1}) >T1 (11.45 mg kg^{-1}) >T7 (11.39 mg kg^{-1}) =T8 (11.42 mg kg^{-1}) >T9 (11.00 mg kg^{-1}).

After 90 days of incubation, available Fe content showed an increased value in all treatments and here also treatment with plantain compost with lime and MOP (T5) reported highest available Fe content with a value of 18.19 mg kg^{-1} and the treatments T7 (lime alone) and T8 (lime with MOP) were on par with each other. The treatment followed as, T5 (18.19 mg kg^{-1}) > T6 (17.19 mg kg^{-1}) > T4 (16.68 mg kg^{-1}) > T3 (15.03 mg kg^{-1}) > T1 (13.24 mg kg^{-1}) > T7 (11.42 mg kg^{-1}) =T8 (11.42 mg kg^{-1}) > T9 (11.00 mg kg^{-1}). The treatments were found significantly different both at 0 and 90 days after incubation.

Table 4.21 Available iron content (mg kg^{-1}) in the soil samples at 0 and 90 days after incubation

Treatments	At 0 days	At 90 days
T1 : Rice straw (35g/box) + MOP (1g K_2O /box)	11.45^{f}	13.24^{e}
T2 : Plantain compost (35g/box) + MOP (1g K_2O /box)	12.00^{d}	16.76^{c}
T3 : Wood ash with FYM (35g/box) + MOP (1g K_2O /box)	11.95^{e}	15.03^{d}
T4 : Rice straw (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	12.73^{c}	16.68^{c}
T5 : Plantain compost (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	14.27^{a}	18.19^{a}
T6 : Wood ash with FYM (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	13.73^{b}	17.19^{b}
T7: Lime (0.8g/box)+ MOP (1g K_2O /box)	11.39^{g}	11.42^{f}
T8 : MOP (1g K_2O /box)	11.38^{g}	11.42^{f}
T9 : control	11.20^{h}	11.00^{g}
CD(0.05)	0.09*	0.09*

* Found significant at 5% level of significance

4.3.9 Available manganese

The available Mn content in soil samples after application of different treatments were analysed at 0 and 90 days after incubation and given in table 4.22. Here also an increasing trend was observed in available Mn content in all treatments except control, from 0 to 90 days of incubation.

During 0 day of incubation, treatments consisted of rice straw with lime and MOP (T4) and plantain compost with lime and MOP were having higher value of Mn content compared to other treatments and the trend in the value of treatments were T4 (36.79 mg kg^{-1}) >T5 (36.30 mg kg^{-1}) > T7 (32.40 mg kg^{-1}) > T1 (32.23 mg kg^{-1}) > T2(31.13 mg kg^{-1}) > T3 (29.89 mg kg^{-1}) > T6 (28.59 mg kg^{-1}) > T8 (27.29 mg kg^{-1}) > T9 (11.08 mg kg^{-1}). After 90 days of incubation, available Mn content has shown an increased value in all treatments except for control treatment which showed a lower value. Here also, T4 and T5 treatment was having higher available Mn content and the trend followed as, T4 (47.82 mg kg^{-1}) > T5 (47.67mg kg^{-1}) > T1 (45.90 mg kg^{-1})> T2 (42.27 mg kg^{-1}) > T7 (39.98 mg kg^{-1}) > T4 (47.60 mg kg^{-1}) > T6 (30.09 mg kg^{-1}) > T8 (27.88 mg kg^{-1}) > T9 (11.03 mg kg^{-1}). The treatments were found significantly different at both the incubation intervals.

Table 4.22 Available manganese content (mg kg^{-1}) content in the soil samples with different treatments at 0 and 90 days after incubation

Treatments	At 0 days	At 90 days
T1 : Rice straw (35g/box) + MOP (1g K_2O /box)	32.23[d]	45.90[c]
T2 : Plantain compost (35g/box) + MOP (1g K_2O /box)	31.13[e]	42.27[d]
T3 : Wood ash with FYM (35g/box) + MOP (1g K_2O /box)	29.89[f]	33.71[f]
T4 : Rice straw (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	36.79[a]	47.81[a]
T5 : Plantain compost (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	36.30[b]	47.67[b]
T6 : Wood ash with FYM (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	28.59[g]	30.09[g]
T7: Lime (0.8g/box)+ MOP (1g K_2O /box)	32.40[c]	39.98[e]
T8 : MOP (1g K_2O /box)	27.29[h]	27.89[h]
T9 : control	11.08[i]	11.03[i]
CD (0.05)	0.04*	0.02*

* Found significant at 5% level of significance

4.3.10 Available copper

The available Cu content in soil samples after application of different treatments was analyzed at 0 and 90 days after incubation and shown in table 4.23. Here also an increasing trend was observed (except control treatment) in all treatments from 0 to 90 days of incubation.

During 0 day of ncubation, treatment containing plantain compost with le and MOP (T5) reported the highest value of Cu content (7.19 mg kg^{-1}) compared to other treatments. It was followed by treatment containing rice straw with lime and MOP (T4) and wood ash with FYM, lime and MOP (T6) with values of 6.19 mg kg^{-1} and 6.003 mg kg^{-1} respectively.

After 90 days of incubation, available Cu content registered an increased value in all treatments and here also, T5 treatment (Plantain compost with lime and MOP) was having higher available Cu content having value 7.87mg kg^{-1} which was again followed by T4 and T6 treatments with values 6.44mg kg^{-1} and 6.19 mg kg^{-1} respectively. The trend in the values of available Cu during 0 and 90 days of incubation followed the same order with different values as, T5 (7.19 mg kg^{-1}), (7.87 mg kg^{-1}) > T4 (6.19mg kg^{-1}), (6.44 mg kg^{-1}) > T6 (6.00 mg kg^{-1}), (6.19 mg kg^{-1}) > T1 (5.49 mg kg^{-1}) , (5.89 mg kg^{-1}) > T3 (5.19 mg kg^{-1}), (5.49 mg kg^{-1}) > T1 (5.00 mg kg^{-1}), (5.39 mg kg^{-1}) > T7 (3.12 mg kg^{-1}), (3.15 mg kg^{-1}) = T8 (3.10 mg kg^{-1}), (3.13 mg kg^{-1}) > T9 (2.10 mg kg^{-1}), (2.83 mg kg^{-1}). The treatments T7 (lime alone) and T8 (lime with MOP) were on par with each other at 0 and 90 days of incubation. The treatments were found significantly different at both the incubation intervals.

Table 4.23 Copper content (mg kg^{-1}) in the soil samples at 0 and 90 days after incubation

Treatments	At 0 days	At 90 days
T1 : Rice straw (35g/box) + MOP (1g K_2O /box)	5.00[f]	5.39[f]
T2 : Plantain compost (35g/box) + MOP (1g K_2O /box)	5.49[d]	5.88[d]
T3 : Wood ash with FYM (35g/box) + MOP (1g K_2O /box)	5.19[e]	5.49[e]
T4 : Rice straw (35g/box) + Lime (0.8g K_2O /box) + MOP (1g/box)	6.19[b]	6.45[b]
T5 : Plantain compost (35g/box) + Lime (0.8g K_2O /box) + MOP (1g/box)	7.19[a]	7.87[a]
T6: Wood ash with FYM (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	6.00[c]	6.19[c]
T7: Lime (0.8g/box)+ MOP (1g K_2O /box)	3.12[g]	3.15[g]
T8 : MOP (1g K_2O /box)	3.10[g]	3.13[g]
T9 : control	2.91[h]	2.83[h]
CD(0.05)	0.03*	0.02*

*found significant at 5 % level of significance

4.3.11 Available zinc

The available Zn content in soil samples after application of different treatments was analyzed at 0 and 90 days after incubation and presented in table 4.24. Here also an increasing trend was observed in all treatments from 0 to 90 days of incubation.

During 0 day of incubation, treatment containing woodash with FYM, lime and MOP (T6) reported the highest value of Zn content (2.797 mg kg^{-1}) compared to other treatments and the treatments T3 (wood ash with FYM) and T5 were on par. The trend in the value followed as, T6 (2.79 mg kg^{-1}) >T3 (2.59 mg kg^{-1}) = T5 (2.59 mg kg^{-1}) > T2 (2.16 mg kg^{-1}) >T4 (1.79 mg kg^{-1}) > T7 (1.59 mg kg^{-1}) > T8 (1.55 mg kg^{-1}) > T1 (1.21 mg kg^{-1}) > T9 (1.10 mg kg^{-1}). After 90 days of incubation, available Zn content has shown an increased value in all treatments and here also, T6 treatment was having higher available Zn content (3.003 mg kg^{-1}) and the trend followed the order, T6 (3.00 mg kg^{-1}) > T5 (2.90 mg kg^{-1}) = T3 (2.89 mg kg^{-1}) > T2 (2.39 mg kg^{-1}) > T4 (2.00 mg kg^{-1}) > T7 (1.85 mg kg^{-1}) > T1 (1.66 mg kg^{-1}) > T8 (1.25 mg kg^{-1}) > T9 (1.09 mg kg^{-1}). Here also the treatments containing plantain compost with lime and MOP (T5) and wood ash with MOP (T3) were on par with each other. The treatments were found significantly different both at 0 and 90 days of incubation.

Table 4.24 Available zinc content (mg kg^{-1}) content of soil samples with different treatments at 0 and 90 days after incubation

Treatments	At 0 days	At 90 days
T1 : Rice straw (35g/box) + MOP (1g K_2O /box)	1.21[g]	1.66[f]
T2 : Plantain compost (35g/box) + MOP (1g K_2O /box)	2.16[c]	2.39[c]
T3 : Wood ash with FYM (35g/box) + MOP (1g K_2O /box)	2.59[b]	2.89[b]
T4 : Rice straw (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	1.79[d]	2.00[d]
T5 : Plantain compost (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	2.59[b]	2.90[b]
T6 : Wood ash with FYM (35g/box) + Lime (0.8g/box) + MOP (1g K_2O /box)	2.79[a]	3.00[a]
T7: Lime (0.8g/box)+ MOP (1g K_2O /box)	1.59[e]	1.86[e]
T8 : MOP (1g K_2O /box)	1.55[f]	1.26[g]
T9 : control	1.10[h]	1.09[h]
CD (0.05)	0.03 *	0.01*

*found significant at 5 % level of significance

4.4 Different forms of K

During incubation study, different forms of K such as exchangeable, non-exchangeable, available, water soluble and total K were determined at 0, 15, 30, 60 and 90 days of incubation.

4.4.1 Total K

The total K content of soil samples with different treatments was determined at 0, 15, 30, 60 and 90 days after incubation and are presented in table 4.25. It showed slight increase in the value over the period of incubation in all the treatments except control which remained more or less constant.

At 0 day of incubation, treatment containing rice straw with lime and MOP (T4) reported the highest total K content with value of 2397.33 mg kg^{-1}, followed by the treatment consisting of rice straw and MOP (T1) and plantain compost with lime and MOP (T5) with values of 2395.00 mg kg^{-1}, and 2328.00 mg kg^{-1}, respectively. The order of value of total K is, T9 (1030.00 mg kg^{-1}) < T8 (1862.00mg kg^{-1},) = T7 (1862.11 mg kg^{-1}) < T3 (2010.00mg kg^{-1}) < T6 (2012.11 mg kg^{-1}) < T2 (2325.12 mg kg^{-1}) < T5 (2328.00mg kg^{-1}) < T1 (2395.00mg kg^{-1}) < T4 (2397.33 mg kg^{-1}). The treatments T8 (MOP alone) and T7 (lime with MOP) were on par with each other.Compared to MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were 1.16%, 1.00%, 1.15%, 1.50%, 1.25%, 1.44% and 1.00% respectively, which clearly shows the highest value under rice straw with lime and MOP treatment (T4).

At 15 days after incubation, total K content among all treatments had shown a slight increment and the highest value was also obtained for T4 treatments (rice straw with lime and MOP) followed by T6 treatment (wood ash, FYM with lime and MOP). The order of magnitude of total K content in all treatments followed as, T9 (1032.33 mg kg^{-1}) < T8 (1862.00 mg kg^{-1}) = T7 (1862.85 mg kg^{-1}) < T3 (2012.22 mg kg^{-1}) =T6 (2012.55 mg kg^{-1}) < T2 (2326.00 mg kg^{-1}) < T5 (2329.55 mg kg^{-1}) < T1 (2395.50 mg kg^{-1}) < T4 (2399.00mg kg^{-1}). The treatments T8 and T7 were on par with each other.

Similarly, the treatments containing wood ash - FYM combination with MOP (T3) and wood ash - FYM combination with lime and MOP (T6) were on par with each other. The percentage increase in all treatments with respect to MOP alone application (T8) were, 1.16%, 1.01%, 1.15%, 1.50%, 1.28%, 1.44% and 1.00% respectively for treatments T1, T2, T3, T4, T5, T6 and T7.

After 30 days of incubation, there also showed a minute increment in the value of total K in all samples with the highest value obtained again for treatment T4 (rice straw with lime and MOP) followed by T6 treatment (Wood ash with FYM lime and MOP). The order of magnitude of all treatments followed again as, T9 (1032.00mg kg^{-1}) < T7 (1863.44 mg kg^{-1}) = T8 (1863.55 mg kg^{-1}) < T3 (2013.09 mg kg^{-1},) = T6 (2013.28 mg kg^{-1})< T2 (2326.88 mg kg^{-1}) <T5 (2330.05 mg kg^{-1})< T1 (2396.05 mg kg^{-1}) < T4 (2399.00 mg kg^{-1}). Here also the treatments T7 and T8 were on par with each other. The treatments T3 and T6 also had similar statistical results. With reference to MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash : FYM with lime and MOP (T6) and lime with MOP (T7) were 1.52%, 1.51%, 1.39%, 1.79%, 1.55%, 1.72% and 1.04% respectively, which clearly shows the highest value under T4 treatment containing rice straw with lime and MOP.

After 60 days of incubation, the magnitude of total K had increased in all treatments compared to previous incubation intervals with the highest value obtained again for T4 treatment containing rice straw with lime and MOP with value 1579.67 mg kg^{-1}, followed by T6 treatment (wood ash, FYM with lime and MOP) and T5 (plantain compost with lime and MOP) with values of 1519.67 mg kg^{-1}, and 1351.33mg kg^{-1} respectively. The decreasing order of total K among different incubation intervals followed the order, T9 (1034.00 mg kg^{-1}) < T8 (1863.04 mg kg^{-1}) = T7 (1865.11 mg kg^{-1}) < T3 (2013.30 mg kg^{-1}) = T6 (2013.88 mg kg^{-1}) < T2 (2327.22 mg kg^{-1}) < T5 (2330.69 mg kg^{-1}) < T1 (2396.68 mg kg^{-1}) < T4 (2400.00 mg kg^{-1}). By comparing MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were 1.17%, 1.01%, 1.16%, 1.50%, 1.28%, 1.44% and 1.00% respectively, which shows the highest value again under T4 treatment containing rice straw with lime and MOP.

After 90 days of incubation, the magnitude of total K content in all treatments has showed a slight decline compared to 60 days after incubation. The highest value was again obtained in T4 treatment with the value of 1573.33 mg kg^{-1}, which was followed by treatment T6 with value of 1515.33 mg kg^{-1}. The order of total K content in all samples followed as, T9 (1033.33 mg kg^{-1}) < T8 (1862.08 mg kg^{-1}) = T7 (1863.11mg kg^{-1}) < T3 (2011.99 mg kg^{-1}) = T6 (2012.00 mg kg^{-1}) < T2 (2325.00 mg kg^{-1}) < T5 (2328.55 mg kg^{-1}) < T1 (2395.63 mg kg^{-1}) < T4 (2398.44 mg kg^{-1}). All the treatments were found significantly different at 0, 15, 30, 60 and 90 days after incubation. The treatments consisting of lime and MOP (T7) and MOP alone (T8) had similar statistical results. Similarly, T3 (wood ash-FYM with MOP) and T6 (wood ash – FYM with lime and MOP) treatments were also on par with each other. By comparing MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were 1.16%, 1.01%, 1.15%, 1.50%, 1.28%, 1.44% and 1.00% respectively, which defines the highest value again under T4 treatment containing rice straw with lime and MOP.

Table 4.25 Total K (mg kg^{-1}) content in the soil samples at different incubation intervals

Treatments	Incubation period (days)				
	0	15	30	60	90
T1: RS (35g/box) +MOP (1g K_2O /box)	2395.00^{b}	2395.50^{b}	2396.05^{b}	2396.68^{b}	2395.63^{b}
T2: PC (35g/box) + MOP (1g K_2O /box)	2325.12^{d}	2326.00^{d}	2326.88^{d}	2327.22^{d}	2325.00^{d}
T3: WA: FYM (35g/box) +MOP (1g K_2O /box)	2010.00^{f}	2012.22^{e}	2013.09^{e}	2013.88^{e}	2011.99^{e}
T4: RS (35g/box) + L (0.8g/box) +MO P (1g K_2O /box)	2397.33^{a}	2399.00^{a}	2399.55^{a}	2400.00^{a}	2398.44^{a}
T5: PC (35g/box) + L (0.8g/box) + MOP (1g K_2O/box)	2328.00^{c}	2329.55^{c}	2330.05^{c}	2330.69^{c}	2328.55^{c}
T6: WA: FYM (35g/box) + L (0.8g/box) +MOP (1g K_2O /box)	2012.11^{e}	2012.55^{e}	2013.28^{e}	2013.33^{e}	2012.00^{e}
T7: L (0.8g/box)+MOP (1g K_2O /box)	1862.11^{g}	1862.85^{f}	1863.44^{f}	1865.11^{f}	1863.11^{f}
T8: (1g K_2O /box)	1860.00^{g}	1862.00^{f}	1862.55^{f}	1863.04^{f}	1862.08^{f}
T9: Control	1030.00^{h}	1030.07^{g}	1031.00^{g}	1032.00^{g}	1031.33^{g}
CD(0.05)	10.03*	7.33*	3.54*	6.21*	12.60*

*found significant at 5% level of significance

4.4.2. Exchangeable K

The exchangeable K content of soil samples with different treatments were analysed at 0, 15, 30, 60 and 90 days after incubation and are given in the table (4.26). The values showed different trends under different treatments. In case of treatments T1 (rice straw with MOP) T2 (plantain compost with MOP) and T3 (Wood ash with FYM with MOP) showed an increased value of exchangeable K from 0 to 90 days after incubation. But in the case ofT4 (rice straw with +MOP), T5 (Plantain compost with lime and MOP), T6 (Wood ash with FYM with lime and MOP), T7 (Lime with MOP) and T8 (MOP alone) treatments, the value increased from 0 to 60days then after 90 days of incubation, the value has decreased. In case of T9 (absolute control treatment) showed a slight decline in the value the value throughout the incubation study.

The magnitude of exchangeable K in treatments at0 day of incubation valued as, T9 (236.22 mg kg^{-1}) < T1 (255.83 mg kg^{-1}) < T8 (298.40 mg kg^{-1}) < T2 (300.42 mg kg^{-1}) < T4 (328.43 mg kg^{-1}) < T5 (338.50 mg kg^{-1}) < T3 (345.85 mg kg^{-1}) < T7 (359.28 mg kg^{-1}) < T6 (392.75 mg kg^{-1}). The increment in percentage under all treatments with respect to MOP alone application (T8) were 0.85%, 1.00%, 1.15%, 1.10%, 1.13%, 1.31% and 1.20% respectively for treatments rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7).

The magnitude of exchangeable K after 15 days of incubation followed as, T9 (231.90 mg kg^{-1}) < T8 (295.30 mg kg^{-1}) < T1 (317.75 mg kg^{-1}) < T7 (363.80 mg kg^{-1}) <T2 (367.55 mg kg^{-1}) < T3 (392.73 mg kg^{-1})< T4 (429.43 mg kg^{-1}) = T5 (429.77 mg kg^{-1}) < T6 (462.90 mg kg^{-1}). Here, the treatments T4 (rice straw with lime and MOP) and T5 (plantain compost with lime and MOP) were on par with each other. By comparing MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 1.07%, 1.24%, 1.32%, 1.45%, 1.45%, 1.56% and 1.23% respectively, which defines the highest value under T6 treatment containing wood ash: FYM combination with lime and MOP.

The values of exchangeable K during 30 days after incubation followed as, T9 (228.00 mg kg^{-1}) < T8 (295.03 mg kg^{-1}) < T7 (360.80 mg kg^{-1}) < T1 (367.33 mg kg^{-1}) < T2 (389.63 mg kg^{-1}) < T3 (399.52 mg kg^{-1}) < T5 (437.80 mg kg^{-1}) < T4 (468.71 mg kg^{-1}) < T6 (458.85 mg kg^{-1}). By comparing MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), woodash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 1.20%, 1.28%, 1.31%, 1.50%, 1.43%, 1.54% and 1.18% respectively, which shows the highest value again under T6 treatment containing wood ash: FYM combination with lime and MOP.

The order of value of exchangeable K after 60 days after incubation given as, T9 (225.44 mg kg^{-1}) < T8 (293.30 mg kg^{-1}) < T1 (381.95 mg kg^{-1}) < T7 (389.00 mg kg^{-1}) < T3 (415.18 mg kg^{-1}) = T2 (416.26 mg kg^{-1}) < T5 (451.68 mg kg^{-1}) < T4 (473.82 mg kg^{-1}) < T6 (491.92 mg kg^{-1}). With reference to MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), woodash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 1.30%, 1.41%, 1.41%, 1.61%, 1.53%, 1.67%, 1.32% respectively, which shows the highest value again under T6 treatment containing wood ash: FYM combination with lime and MOP.

The trend in the value of exchangeable K among all treatments after 90 days of incubation followed as, T9 (218.68 mg kg^{-1}) < T8 (270.32 mg kg^{-1}) < T7 (360.21 mg kg^{-1}) < T1 (399.72 mg kg^{-1}) < T3 (436.36 mg kg^{-1}) < T5 (445.53 mg kg^{-1}) < T2 (451.12 mg kg^{-1}) < T6 (465.40 mg kg^{-1}) < T4 (470.15 mg kg^{-1}). The treatments were found significantly different at all incubation intervals. With reference to MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), woodash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 1.38%, 1.56%, 1.51%, 1.63%, 1.54%, 1.61% and 1.32% respectively, which shows the highest value under T4 treatment containing rice straw with lime and MOP.

Table 4.26 Exchangeable potassium (mg kg^{-1}) content in the soil samples at different incubation intervals

Treatments	Incubation period (days)				
	0	15	30	60	90
T1: RS (35g/box) +MOP (1gK_2O /box)	255.83^{h}	317.75^{f}	367.33^{f}	381.95^{f}	399.72^{f}
T2: PC (35g/box) + MOP (1gK_2O /box)	300.42^{f}	367.55^{d}	389.63^{e}	416.27^{d}	451.12^{c}
T3: WA: FYM (35g/box) +MOP (1gK_2O /box)	345.82^{c}	392.73^{c}	399.52^{d}	415.18^{d}	436.37^{e}
T4: RS (35g/box) + L (0.8g/box) +MO P (1gK_2O /box)	328.43^{e}	429.43^{b}	468.71^{a}	493.82^{b}	470.15^{a}
T5: PC (35g/box) + L (0.8g/box) + MOP (1g K_2O/box)	338.50^{d}	429.77^{b}	437.80^{c}	451.68^{c}	445.53^{d}
T6: WA: FYM (35g/box) + L (0.8g/box) +MOP (1gK_2O /box)	392.75^{a}	462.90^{a}	458.85^{a}	465.92^{b}	360.21^{b}
T7: L (0.8g/box)+MOP (1gK_2O /box)	359.28^{b}	360.80^{e}	365.25^{g}	389.00^{e}	270.32^{g}
T8: (1gK_2O /box)	298.40^{g}	295.30^{g}	295.03^{h}	283.30^{g}	218.32^{h}
T9: Control	236.22^{i}	231.90^{h}	228.00^{i}	225.44^{h}	218.68^{i}
CD(0.05)	2.48*	2.70*	2.18*	2.31*	2.34*

*found significant at 5% level of significance

4.4.3. Non Exchangeable K

The non-exchangeable K content of the soil samples under different treatments were determined at 0, 15, 30, 60 and 90 days after incubation (table 4.27). Here, an increasing trend in the value was observed up to 60 days which was later followed by decline towards 90 days of incubation. In case of control treatment (T9) it showed more or less a constant value throughout the incubation period.

During 0 day after incubation, treatment consisting of rice straw with lime and MOP (T4) reported the highest value of 1003.66 mg kg^{-1}, which was followed by treatment containing rice straw with lime and MOP (T6) with value of 887.75 mg kg^{-1}.

The order in the value of non- exchangeable K were obtained as T4 (1003.66mg kg^{-1}) > T6 (887.75 mg kg^{-1}) > T7 (767.08 mg kg^{-1}) > T5 (690.83 mg kg^{-1}) = T1 (672.00mg kg^{-1}) > T3 (625.25mg kg^{-1}) > T2 (604.66 mg kg^{-1}) > T8 (638.83 mg kg^{-1}) > T9 (600.00 mg kg^{-1}). With reference to MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 1.05%, 0.94%,0.97%, 1.57%, 1.08%, 1.38% and 1.20% respectively, which shows the highest value under T4 treatment containing rice straw with lime and MOP.

After 15 days of incubation, again treatment T4 (rice straw with lime and MOP) reported the highest value. The trend in all treatments followed as, T9 (598.83 mg kg^{-1}) < T8 (859.75 mg kg^{-1}) < T2 (942.33 mg kg^{-1}) = T7 (941.92 mg kg^{-1}) < T3 (1015.16 mg kg^{-1}) < T1 (1057.66 mg kg^{-1}) < T5 (1189.50 mg kg^{-1}) < T6 (1320.33 mg kg^{-1}) < T4 (1428.33mg kg^{-1}). With reference to MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were 1.23%, 1.09%, 1.18%, 1.66%, 1.38%, 1.53% and 1.09% respectively, which shows the highest value under T4 treatment containing rice straw with lime and MOP.

After 30 days of incubation, T4 treatment containing rice straw with lime and MOP again reported the highest value of non-exchangeable K which was followed by woodash with FYM with lime and MOP (T6) with a value of 1550.17 mg kg^{-1}. The order of the values from all treatments were reported as, T4 (1683.33 mg kg^{-1}) >T6 (1550.17 mg kg^{-1}) > T1 (1375.58 mg kg^{-1})> T5 (1311.33 mg kg^{-1})>T2 (1283.50 mg kg^{-1}) > T3 (1172.66 mg kg^{-1}) > T7 (948.92 mg kg^{-1}) = T8 (911.25mg kg^{-1}) > T9 (594.33 mg kg^{-1}) respectively. By comparing with MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 1.50%, 1.40%, 1.28%, 1.84%, 1.43%, 1.70%, and 1.04% respectively, which shows the highest value under T4 treatment containing rice straw with lime and MOP.

During 60 days after incubation again T4 treatment including rice straw with lime and MOP again reported the highest value and the trend followed as, T4 (1726.67mg kg^{-1}) > T6 (1557.67 mg kg^{-1})> T1 (1363.66 mg kg^{-1}) > T5 (1345.42 mg kg^{-1}) > T2 (1278.42 mg kg^{-1}) > T3(1259.67 mg kg^{-1})> T7 (790.75 mg kg^{-1})> T8 (694.40 mg kg^{-1}) > T9 (590.00 mg kg^{-1}) respectively. By comparing with MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 1.96%, 1.84%, 1.81%, 2.48%, 1.93%, 2.24% and 1.13% respectively, which shows the highest value again under T4 treatment containing rice straw with lime and MOP.

After 90 days of incubation, T4 treatment containing rice straw with lime and MOP again reported the highest value of non-exchangeable K. The increasing order of magnitude obtained as, T9 (583.33 mg kg^{-1}) <T8 (685.50 mg kg^{-1}) < T7 (691.08 mg kg^{-1}) < T3 (902.92 mg kg^{-1}) < T2 (972.08 mg kg^{-1}) < T5 (1104.66 mg kg^{-1}) < T1 (1285.50 mg kg^{-1}) < T6 (1330.66mg kg^{-1}) < T4 (1541.50 mg kg^{-1}). By comparing with MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 1.87%, 1.41%, 1.31%, 2.24%, 1.61%, 1.94% and 1.00% respectively, which again shows the highest value under T4 treatment containing rice straw with lime and MOP.

Table 4.27 Non-exchangeable K (mg kg^{-1}) content in the soil samples at different incubation intervals

Treatments	Incubation period (days)				
	0	15	30	60	90
T1: RS (35g/box) +MOP (1gK$_2$O /box)	672.66^{d}	1057.66^{d}	1375.58^{c}	1363.66^{c}	1285.50^{c}
T2: PC (35g/box) + MOP (1gK$_2$O /box)	604.66^{f}	942.33^{f}	1283.50^{d}	1278.42^{e}	972.08^{e}
T3: WA: FYM (35g/box) +MOP (1gK$_2$O /box)	625.25^{e}	1015.16^{e}	1172.66^{e}	1259.67^{f}	902.92^{f}
T4: RS (35g/box) + L (0.8g/box) +MO P (1gK$_2$O /box)	1003.66^{a}	1428.33^{a}	1683.83^{a}	1726.67^{a}	1541.50^{a}
T5: PC (35g/box) + L (0.8g/box) + MOP (1g K$_2$O/box)	690.83^{d}	1189.50^{c}	1311.33^{cd}	1345.42^{d}	1104.66^{d}
T6: WA: FYM (35g/box) + L (0.8g/box) +MOP (1gK$_2$O /box)	887.75^{b}	1320.33^{b}	1550.17^{b}	1557.67^{b}	1330.66^{b}
T7: L (0.8g/box)+MOP (1gK$_2$O /box)	767.08^{c}	941.92^{f}	948.92^{f}	790.75^{g}	691.08^{g}
T8: (1gK$_2$O /box)	638.83^{e}	859.75^{g}	911.25^{f}	694.42^{h}	685.50^{h}
T9: Control	600.00^{g}	598.83^{h}	594.33^{g}	590.00^{i}	583.33^{i}
CD(0.05)	18.86*	10.24*	67.45*	13.14*	37.44*

*found significant at 5% level of significance

4.4.4 Available K

The available K content of soil samples under different treatments were analyzed at 0, 15, 30, 60 and 90 days after incubation (table 4.28). Here, it showed an increasing trend in the value of available K in all treatments during 0, 15, 30 and 60 days of incubation and later it decreased during 90 days after incubation. In case of T9 treatment (absolute control), it showed a more or less constant value throughout the incubation period.

During 0 day of incubation, the treatment consisting of plantain compost with lime and MOP (T5) reported the highest content in available K with a value of 655.83 mg kg^{-1}, followed by T6 treatment containing wood ash-FYM with lime with MOP with a value of 626.25 mg kg^{-1}. The trend in the values of the treatments followed as, T9 (333.33 mg kg^{-1}) <T8 (362.50mg kg^{-1}) < T7 (386.25 mg kg^{-1}) < T1 (548.33 mg kg^{-1}) < T4 (568.33 mg kg^{-1}) < T3 (583.75 mg kg^{-1}) < T2 (620.83 mg kg^{-1}) =T6 (626.25 mg kg^{-1}) < T5 (655.83 mg kg^{-1}). By comparing with MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 1.51%, 1.71%, 1.61%, 1.56%, 1.80%, 1.62% and 1.06% respectively, which shows the highest value under T5 treatment containing plantain compost with lime and MOP.

After 15 days of incubation, treatment T5 that include plantain compost with lime and MOP again registered the highest value, followed again by T6 treatment containing wood ash, FYM with lime and MOP. The increasing trend of available K under all treatments followed as, T9 (337.50mg kg^{-1}) < T8 (376.25 mg kg^{-1}) < T7 (397.08mg kg^{-1}) < T1 (598.33 mg kg^{-1}) < T3 (610.83mg kg^{-1}) < T4 (626.66 mg kg^{-1}) < T2 (643.33 mg kg^{-1}) < T6 (666.66 mg kg^{-1}) < T5 (692.50 mg kg^{-1}). By comparing with MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 1.59%, 1.70%, 1.62%, 1.66%, 1.84%, 1.77% and 1.00% respectively, which again shows the highest value under T5 treatment containing plantain compost with lime and MOP.

After 30 days of incubation, treatment T5 (plantain compost with lime and MOP) again reported higher value of 722.92 mg kg^{-1} which was again followed by T6 treatment (wood ash, FYM with lime and MOP) with the value of 696.66 mg kg^{-1} and treatment T2 containing plantain compost with MOP (695.83 mg kg^{-1}) which were on par with each other. The order of magnitude of the treatments followed as, T9 (350.00 mg kg^{-1}) < T8 (395.00mg kg^{-1}) = T7 (402.08 mg kg^{-1}) < T1 (627.08 mg kg^{-1}) < T3 (651.25 mg kg^{-1}) < T4 (666.25 mg kg^{-1}) < T2 (695.83 mg kg^{-1}) < T6 (696.66 mg kg^{-1}) < T5 (722.91 mg kg^{-1}). By comparing with MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 1.65%, 1.79%, 1.72%, 1.72%, 1.85%, 1.78% and 1.04% respectively, which again shows the highest value under T5 treatment containing plantain compost with lime and MOP.

After 60 days of incubation, treatment T5 that contained plantain compost with lime and MOP once again registered high value of available potassium. The order of magnitude of available K in all treatments followed as, T9 (350.00 mg kg^{-1}) < T8 (402.92 mg kg^{-1}) < T7 (421.25mg kg^{-1}) < T1 (668.33 mg kg^{-1}) < T3 (695.00 mg kg^{-1}) = T4 (695.00 mg kg^{-1}) < T2 (722.91 mg kg^{-1}) = T6 (720.00 mg kg^{-1}) < T5 (747.92 mg kg^{-1}). By comparing with MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were 1.65%, 1.79%, 1.72%, 1.72%, 1.85%, 1.78% and 1.04% respectively, which again shows the highest value under T5 treatment containing plantain compost with lime and MOP.

But after 90 days of incubation, the values of available K under all treatments showed a decline and the treatment T5 containing plantain compost with lime and MOP registered highest content of available K with the value of 720.00 mg kg^{-1} followed by T6 treatment that include Wood ash with FYM with lime and MOP with the value of 691.66mg kg^{-1}. The treatments containing plantain compost with MOP (T2) and wood ash with FYM with lime and MOP (T6) were on par with each other with the similar values of 694.17 mg kg^{-1}and 691.66 mg kg^{-1}respectively. The order of magnitude of available K content under all treatments followed as, T9 (350.00 mg kg^{-1}) < T8 (385.83 mg kg^{-1}) < T7 (394.58 mg kg^{-1}) < T1 (637.50 mg kg^{-1}) < T3 (660.42 mg kg^{-1}) = T4 (660.83 mg kg^{-1}) < T2 (694.17mg kg^{-1}) =T6 (691.60mg kg^{-1}) < T5 (720.00mg kg^{-1}). All the treatments were found significantly different at all the incubation periods. By comparing with MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 1.65%, 1.79%, 1.71%, 1.71%, 1.86%, 1.79% and 1.02%   respectively, which shows the highest value of available K under T4 treatment containing rice straw with lime and MOP.

Table 4.28. Available K (mg kg^{-1}) content in the soil samples at different incubation intervals

Treatments	Incubation period (days)				
	0	15	30	60	90
T1: RS (35g/box) +MOP (1gK_2O /box)	548.33^{e}	598.33^{f}	627.08^{e}	668.33^{d}	637.50^{d}
T2: PC (35g/box) + MOP (1gK_2O /box)	620.83^{b}	643.33^{c}	695.83^{b}	722.91^{b}	694.17^{b}
T3: WA: FYM (35g/box) +MOP (1gK_2O /box)	583.75^{c}	610.83^{e}	651.25^{d}	695.00^{c}	660.42^{c}
T4: RS (35g/box) + L (0.8g/box) +MO P (1gK_2O /box)	568.33^{d}	626.66^{d}	666.25^{c}	695.00^{c}	660.83^{c}
T5: PC (35g/box) + L (0.8g/box) + MOP (1g K_2O/box)	655.83^{a}	692.50^{a}	722.91^{a}	747.92^{a}	720.00^{a}
T6: WA: FYM (35g/box) + L (0.8g/box) +MOP (1gK_2O /box)	626.25^{b}	666.66^{b}	696.66^{b}	720.00^{b}	691.66^{b}
T7: L (0.8g/box)+MOP (1gK_2O /box)	386.25^{f}	397.08^{g}	402.08^{f}	421.25^{e}	394.58^{e}
T8: (1gK_2O /box)	362.50^{g}	376.25^{h}	395.00^{f}	402.92^{f}	385.83^{f}
T9: Control	333.33^{h}	337.50^{i}	350.00^{g}	350.00^{g}	350.00^{g}
CD(0.05)	13.30*	7.50*	7.65*	7.40*	7.36*

*found significant at 5% level of significance

4 4.5 Water soluble K

The water soluble K content of soil samples under the treatments were estimated and data obtained showed an increasing trend in the value of water soluble K in all treatments up to 60 days of incubation (table 4.29). Later showed decrease in value after 90 days of incubation. In case of T9 treatment (absolute control), the values showed a slight decline throughout the incubation period.

During 0 day of incubation, treatment T6 that contain woodash with FYM with lime and MOP registered the highest value of 296.55 mg kg^{-1}. The order of increasing magnitude of water soluble K during 0 day of incubation followed as, T9 (112.53 mg kg^{-1}) < T8 (142.85 mg kg^{-1}) < T7 (193.93 mg kg^{-1}) < T4 (239.90 mg kg^{-1}) < T3 (275.01 mg kg^{-1}) < T2 (283.33 mg kg^{-1}) < T5 (287.75 mg kg^{-1}) < T1 (292.50 mg kg^{-1}) < T6 (296.55 mg kg^{-1}). By comparing with MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 2.04%, 1.98%, 1.92%, 1.67%, 2.01%, 2.07% and 1.35% respectively, which shows the highest value of available K under T6 treatment containing wood ash : FYM combination with lime and MOP.

After 15 days of incubation, treatment T6 containing wood ash with FYM, lime and MOP again reported the highest value which was followed by treatment containing plantain compost with lime and MOP (T5) with value of 317.73 mg kg^{-1}. The treatments T2 (plantain compost with MOP) and T5 (plantain compost with lime and MOP) were on par with each other. The value among all treatments followed as, T9 (111.43 mg kg^{-1}) < T8 (175.36 mg kg^{-1}) < T7 (216.95 mg kg^{-1}) < T4 (273.48 mg kg^{-1}) < T3 (306.01 mg kg^{-1}) < T1 (308.91 mg kg^{-1}) < T2 (317.45 mg kg^{-1}) = T5 (317.73 mg kg^{-1}) < T6 (330.43 mg kg^{-1}). By comparing with MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 1.76%, 1.81%, 1.74%, 1.55%, 1.81%, 1.88% and 1.23% respectively, which again shows the highest value of available K under T6 treatment containing wood ash : FYM combination with lime and MOP.

During 30 days after incubation, again wood ash with FYM, lime and MOP treatment (T6) registered the highest value and their order of treatments followed as, T6 (345.31 mg kg^{-1}) > T5 (344.28 mg kg^{-1}) > T2 (332.86 mg kg^{-1}) > T3 (320.48 mg kg^{-1}) > T1 (316.41 mg kg^{-1}) > T4 (286.70 mg kg^{-1}) > T7 (232.66 mg kg^{-1}) > T8 (190.13 mg kg^{-1}) > T9 (111.00 mg kg^{-1}). With reference to MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 1.66%, 1.75%, 1.68%, 1.50%, 1.81%, 1.81%, 1.22% respectively, which again shows the highest value of available K under T6 treatment containing wood ash : FYM combination with lime and MOP.

But, after 60 days of incubation, T6 once again reported the highest value and the trend in the value followed as, T6 (349.83 mg kg^{-1}) > T5 (346.83 mg kg^{-1}) > T2 (334.98 mg kg^{-1}) > T3 (323.98 mg kg^{-1}) > T1 (322.63 mg kg^{-1}) > T4 (288.68 mg kg^{-1}) > T7 (236.41 mg kg^{-1}) > T8 (192.53 mg kg^{-1}) > T9 (110.31 mg kg^{-1}). By comparing with MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 1.67%, 1.73%, 1.68%, 1.49%, 1.80%, 1.81% and 1.22% respectively, which again shows the highest value of available K under T6 treatment containing wood ash : FYM combination with lime and MOP.

After 90 days of incubation, treatment T6 containing wood ash with FYM, lime and MOP again reported the highest value followed by plantain compost with MOP treatment (T2) and the order followed as T9 (108.82 mg kg^{-1}) < T8 (180.85 mg kg^{-1}) <T7 (193.20 mg kg^{-1}) < T4 (248.93 mg kg^{-1}) < T1(265.70 mg kg^{-1}) < T3 (268.05 mg kg^{-1}) < T5 (285.01 mg kg^{-1}) < T2 (298.05 mg kg^{-1}) < T6 (317.80 mg kg^{-1}). The treatments were found significantly different under all incubation intervals. By comparing with MOP alone treatment (T8), the increase in percentage of total K in treatments containing, rice straw with MOP (T1) plantain compost with MOP (T2), wood ash: FYM with MOP (T3), rice straw with lime and MOP (T4), plantain compost with lime and MOP (T5), wood ash: FYM with lime and MOP (T6) and lime with MOP (T7) were, 1.46%, 1.64%, 1.48%, 1.37%, 1.57%, 1.75% and 1.06% respectively. Here also the value of water soluble K shows the highest value of available K under T6 treatment containing wood ash: FYM combination with lime and MOP.

Table 4.29 Water soluble K (mg kg^{-1}) in the soil samples at different incubation Intervals

Treatments	Incubation period (days)				
	0	15	30	60	90
T1: RS (35g/box) +MOP (1gK_2O /box)	292.50[b]	308.91[c]	316.41[e]	322.63[e]	265.70[e]
T2: PC (35g/box) + MOP (1gK_2O /box)	283.33[d]	317.45[b]	332.86[c]	334.98[c]	298.05[b]
T3: WA: FYM (35g/box) +MOP (1gK_2O /box)	275.01[e]	306.01[d]	320.48[d]	323.98[d]	268.63[d]
T4: RS (35g/box) + L (0.8g/box) +MOP (1gK_2O /box)	239.90[f]	273.48[e]	286.70[f]	288.68[f]	248.93[f]
T5: PC (35g/box) + L (0.8g/box) + MOP (1g K_2O/box)	287.75[c]	317.73[b]	344.28[b]	346.83[b]	285.01[c]
T6: WA: FYM (35g/box) + L (0.8g/box) +MOP (1gK_2O /box)	296.55[a]	330.43[a]	345.31[a]	349.98[a]	317.80[a]
T7: L (0.8g/box)+MOP (1gK_2O /box)	193.93[g]	216.95[f]	232.66[g]	236.41[g]	193.20[g]
T8: MOP (1gK_2O /box)	142.85[h]	175.36[g]	190.13[h]	192.53[h]	180.85[h]
T9: Control	112.53[i]	111.43[h]	111.00[i]	110.31[i]	108.82[i]
CD (0.05)	0.52*	1.67*	0.19*	0.14*	0.23*

*found significant at 5% level of significance

Discussion

5. DISCUSSION

The results obtained in the present investigation entitled "Utilisation of potassium rich crop residues for retention of potassium in lateritic soil" are discussed in this chapter under the following headings:

5.1 Characterisation of rice straw and plantain compost

5.1.1 Decomposition dynamics of rice straw and potassium release

5.1.1.1Physico-chemical properties of rice straw

5.1.1.2 Decomposition rate of rice straw

5.1.1.3 Extent of potassium release from rice straw
5.1.2 Preparation of plantain compost and its characterisation

5.2 Sorption study

5.2.1 Potassium sorption on rice straw

5.2.2 Potassium sorption on plantain compost

5.3 Incubation study

5.3.1 Physico-chemical properties of soil

5.3.1.1 Soil pH

5.3.1.2 Electrical conductivity

5.3.1.3 Soil organic carbon

5.3.1.4 Available nitrogen

5.3.1.5 Available phosphorous

5.3.1.6. Available calcium

5.3.1.7 Available magnesium

5.3.1.8 Available sulphur

5.3.1.9 Available iron

5.3.1.10 Available manganese

5.3.1.11 Available copper

5.3.1.12 Available zinc

5.2 Different forms of potassium

5.2.1 Total K

5.2.2 Exchangeable K

5.2.3 Non-exchangeable K

5.2.4 Available K

5.2.5 Water soluble K

5.1 Characterisation of rice straw and plantain compost

The physico- chemical properties of rice straw and the plantain compost that was prepared by vermi technology was characterized before the initiation of experiment and are discussed here.

5.1.1 Decomposition dynamics of rice straw and potassium release

The decomposition dynamics of rice straw was studied along with its potassium release rate.Physico -chemical properties of rice straw and plantain compost prepared by vermi technology was determined.

5.1.1.1Physico-chemical properties of rice straw

The data pertaining tophysico-chemical properties of rice straw and plantain compost are shown in the figure 1. Rice straw has registered a slight acidic pH of 5.8. Among the macro nutrients the content of potassium was higher than that of nitrogen and phosphorous. It might be due to undecomposed nature of rice straw. Since it is the residues obtained after harvest of paddy, it contains as many nutrients as that were present in live plant tissues during their growth and development.

5.1.1.2Decomposition rate of rice straw

The rate of decomposition of rice straw showed an increasing trend with increase in the time period (Fig.2). The rate of increase was lower at 7days after incubation followed by a quick increase at 14, 30, 60 and 90 days after incubation. There are some factors that determine the rate of decomposition. Incorporation of rice straw as mulch decompose more rapidly than surface application under field condition (Sain and Broadbent, 1977). The rate of decomposition also depends upon the method of incorporation, length of the chopped straw, litter quality, material composition, structure and external factors such as moisture content and amount of carbon dioxide present in the soil (Zhu *et al.*, 2013).Therefore, adequate time period has to be given for its complete decomposition to ensure effectiveness and production efficiency.

In the present study, the decomposition rate accounted for about 51.9% of the total mass of rice straw after 90 days of incubation period. This results depicts that decomposition rate of rice straw consist of two phases (i) rapid decomposition period and (ii) slow decomposition period. The easily decomposable materials such as lipids, carbohydrates and starch which account for less than 25% of the straw get quickly decomposed. But rice straw mainly consists of slowly decomposable materials like cellulose (38%) hemicellulose (25%) and lignin (15%)), that takes more time for breakdown into simple substances (Nguayen*et al.,* 2019). They are made up of complex structure and contains some components that are difficult to decompose(Sun*et al.,* 2021).Similar findings were registered by Liao *et al*. (2013) from their study on decomposition dynamics of rice straw.

The incorporation of straw along with different fertilizers increased the straw decomposition which was assigned by the greater biomass and diversity of fungi and bacteria (Zhao *et al.,* 2019). So the rate of decomposition can be enhanced by focusing on different rate of nitrogen application through organic matter, different method of incorporation and combined application of straw with other fertilizers or with any decaying agents (Guan *et al.,* 2020).

Fig 1. Nutrient contents in rice straw and plantain compost

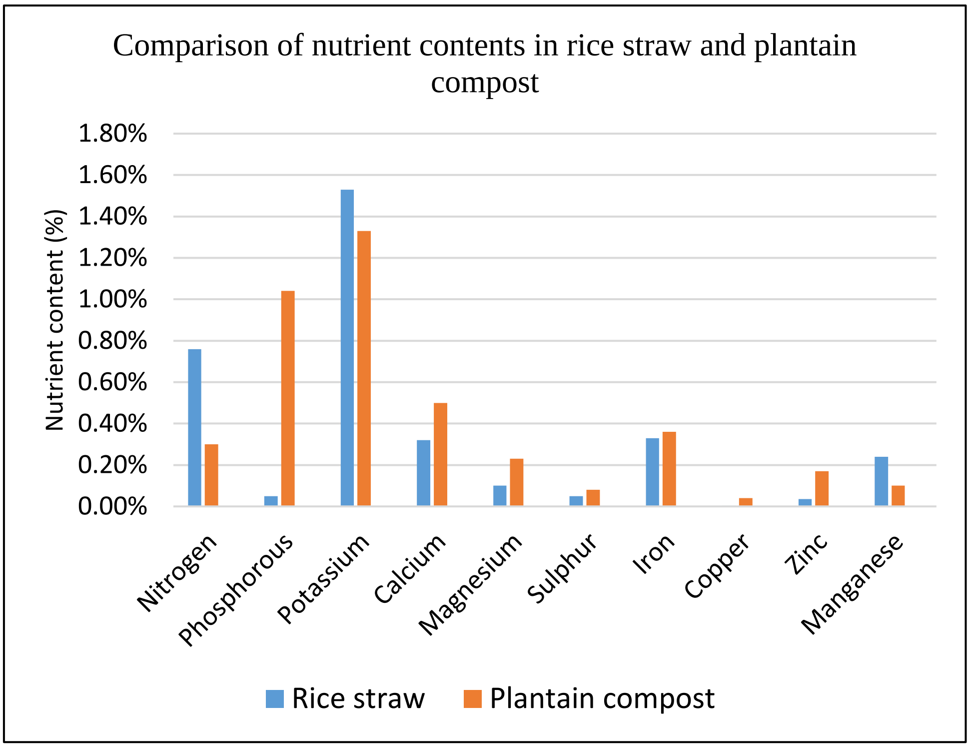
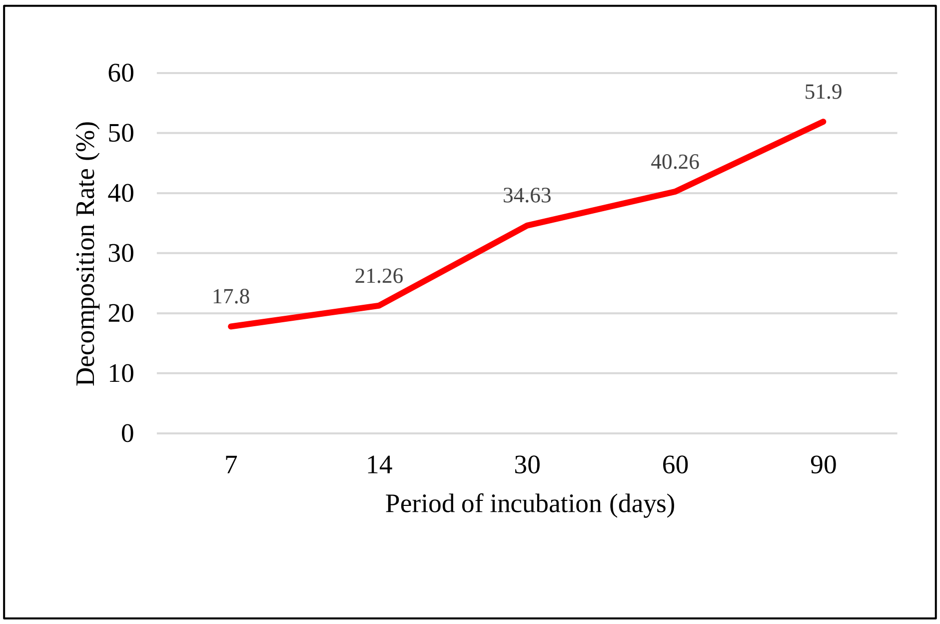


Fig.2 Decomposition pattern of rice straw in soil



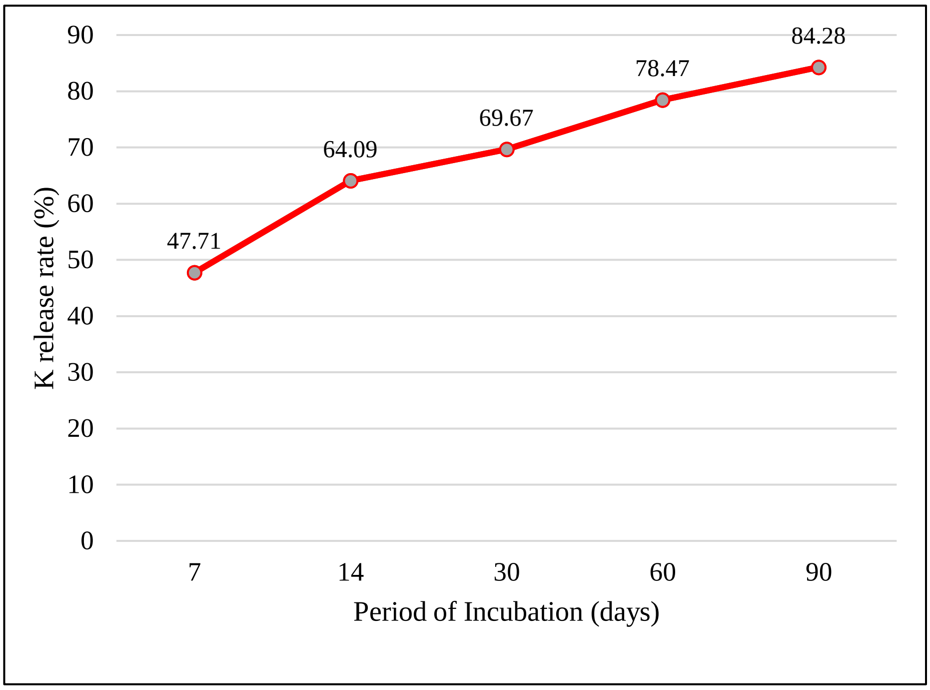
5.1.1.3 Extent of potassium release from rice straw

The data showed an increment in the rate of potassium release from straw (Fig 3). As the decomposition rate increased, the K release rate has also increased that resulted in increase in the availability of potassium in the soil. From the graph it is clear that a steady increase in the K release was from 7 towards 14 days of decomposition. Because, K^+ ions are highly mobile in plant tissue that has showed maximum release during initial days (Liao *et al.*, 2013). Thereafter it showed only slight increase in the rate of release. Therefore, decomposition and nutrient release are greatly determined by the biochemical composition and C/N ratio of organic amendments (Kumar *et al.*, 2019).

Similar findings were also noticed by Rodriguez Lizana*et al.* (2010) regarding K release from sunflower crop residue. Therefore, incorporation of rice straw under conservation tillage require an external application of K to the soil after some days of decomposition of the straw.

A study conducted by Sun *et al.* (2021) revealed that cereal straw such as maize and rice reported highest release rate of K followed by P and N. The reason might be due to highest content of potassium than nitrogen and phosphorous and most of the K^+ ions are in water soluble ionic form that are easily mobile (Wu *et al.*, 2011).

Fig. 3. Rate of potassium release from rice straw at different incubation intervals



5.1.2 Preparation of plantain compost and its characterisation

The plantain compost was prepared at Banana Research Station, Kannara under vermi technology and it took about 1.5 months for preparation. It had an alkaline pH mainly due to presence of bacteria that prefer to live under alkaline condition. The products released by earthworm such as vermicast has promoted the growth of bacteria that has maintained the alkaline pH. Comparing the macronutrients, K content (1.33%) was higher than that of nitrogen and phosphorous. The reason might be that banana plants mainly Nendran variety has a NPK ratio of 190:115:300 g/plant which shows the maximum uptake of K compared to N and P (KAU, 2016). So the banana crop residues obtained after the harvest may also contain higher amount of K compared to other macro nutrients. The Ca content (0.50%) was higher compared to other secondary nutrients. Among the micronutrients, Fe content (0.36%) was higher compared to Cu, Zn and Mn.

Comparing both rice straw and plantain compost, the K content was slightly higher in rice straw might be due to its undecomposed nature. The amount of total carbon was also higher in rice straw compared to plantain compost. The reason is that the decomposed material contains lesser carbon than the undecomposed material because in the former, rate of mineralisation is more compared to the latter that has resulted in the conversion of materials from organic to inorganic forms. The moisture content was higher in rice straw than plantain compost. Since rice straw was obtained as a fresh crop residue which was undecomposed, the water content was more compared to processed compost.

Experiment 2. Sorption study

5.2 Sorption study

The results obtained in the sorption study conducted on rice straw and plantain compost with different levels of KCl are discussed below:

5.2.1 Potassium adsorption on rice straw

Rice straw serves as one of the best bioadsorbent among crop residues especially regarding its ability of reducing pollution caused by heavy metalssuch as Cd(II) and Hg(II) (Rocha *et al.,* 2009) along with its ability of retention of metal ions like K^+ by forming organic ligands (Ke*et al.,* 2009). In the present study it was seen thatthe magnitude of K adsorption increased with the concentration of KCl in the equilibrium solution (fig 4). It was due to the reason of higher concentration of K^+ ions in KCl solution compared to that of rice straw. As per the diffusion principle, solute particles move from its higher concentration to its lower concentration. Hence K^+ ions move from solution to adsorbent phase and saturate it.

Li *et al*. (2014) from their study observedthat the crop residues like rice straw which was subjected to decomposition periods could adsorb the K^+ ions from the ambient surrounding which contain different levels of K^+ions in the solution. The amount of K^+ ions that were removed from different levels of solution were completely adsorbed on the rice straw. But in the case of 0mgK/20 ml solution rather than adsorption, desorption has taken place mainly due to absence of K^+ ions in the solution so that the K^+ present in rice straw moved towards the solution. The capacity of adsorption also increased with increase in decomposition period and the value reached the maximum at 90 days after decomposition. The fineness of the material also had increased due to increased rate of decomposition which has resulted in greater surface area for adsorption. Therefore, the same level of KCl solution at different decomposition period showed higher magnitude of adsorption with the advancement of decomposition period.

Generally, adsorption of metal ions depends on both physical adsorption and chemical adsorption among which latter is dominated as stated by Ke*et al*. (2009), who noticed that rice straw coupled with metal ions to form organic ligands. But the stability of alkali metals like Li, Na and K in forming organic ligands is weak. So the K^+ ions first get adsorbed on rice straw surface and the fractional K^+ moves to the active sites of rice straw particles to form organic ligand. Later, the water present in these active sites moves to the residue surface in order to maintain the equilibrium with the surrounding solution. Since the stability constant of K^+ ions is lower compared to Al^{3+}, Ca^{2+} and Mg^{2+}, the organic complex formed get slowly released.So these complexes slowly get broken down that results in continuous slow release of ions into the soil so that plants can easily absorb them in readily available form. So, as the concentration of external solution increases, rate of adsorption also increases thus resulting in continuous release of ions in long run.

Adsorption isotherm is a curve that explains about the variation in the amount of ions adsorbed on the adsorbent with concentration at constant temperature. The curve was plotted for rice straw and plantain compost against equilibrium concentration value (Ce) on X axis and quantity adsorbed (Qe) on Y axis. Singh and Jones (1975) stated that equilibrium K concentration seems to provide a better index of soil fertility. The value of slope of the curve determines the buffering capacity of the material. In case of rice straw as decomposition period increased, the slope of the curve also has increased that determined high buffering capacity of the rice straw to release the K^+ ions into the soil solution. This increase in the buffering capacity might be due to presence of more exchangeable sites in the rice straw that has occurred due to increase in the CEC as the decomposition has prevailed.

The adsorption curve was fitted on Freundlich adsorption isotherm with R^2 value greater than 0.8. The model was characterized by adsorption intensity factor 1/n and Kf factor that determines the binding strength. The value of 1/n greater than 1 determines good adsorption intensity of the metal ion onto the adsorbent (Mouni*et al.*, 2011). Here, as the decomposition increases, the value of adsorption intensity had also increased with the highest value of 1.45 after 90 days that showed highest intensity of adsorption. The Kffactor which determines the binding strength showed a declining trend which showed that as the decomposition prevailed the bonding between the adsorbent and adsorbate (K^+ ions) became weak thereby increasing the rate of release of K^+ ions into the soil. The Freundlich isotherm has become more linear with the advancement of decomposition. The adsorption curve was not fitted into Langmuir adsorption isotherm because at lower concentrations higher quantity of adsorption was not noticed which is observed in the Langmuir isotherm. Although Langmuir adsorption examine the adsorption as a chemical aspect with assumption that it occurs uniformly on the active sites of the surface (Langmuir, 1918) whereas Freundlich adsorption isotherm assumes a heterogeneous surface with an exponential distribution of active sites and their binding energies (Freundlich, 1906).

5.2.2 Potassium adsorption on plantain compost

The adsorption of K in the prepared plantain compost showed a similar pattern same as in rice straw(fig 5). Since the particles are finer than rice straw, the adsorption rate had a positive value even in the lower concentration. But at 0 mg K solution, it showed desorption that has resulted in the K movement to the solution. So as the level of KCl solution increased, the rate of adsorption has also increased due to higher K^+ ions in the solution that got adsorbed on the surface of compost. The adsorption curve of plantain compost showed a higher buffering capacity because of highest value of CEC compared to rice straw that has resulted greater ability of the material to release K^+ ions into the soil. The graph was also fitted on Freundlich adsorption isotherm with highest intensity of adsorption with value of 3.22 compared to rice straw (2.25). It also registered lowest binding strength due to presence of lesser binding sites that resulted in greater rate of release of ions into the soil.

In the case of rice straw, it was only partially decomposed and 80 percent of it had a size of >0.5mm at 90 days after incubation and this material was used for the adsorption study. But in the case of plantain compost, it was a fully composted material and most of the particles had a size of < 0.25 mm. The difference in the particle size of these two organic K resources could have been the reason for the difference in the magnitude of adsorption of K by these materials.

Fig 4. Potassium adsorption on rice straw (mg g^{-1}) under different incubation intervals

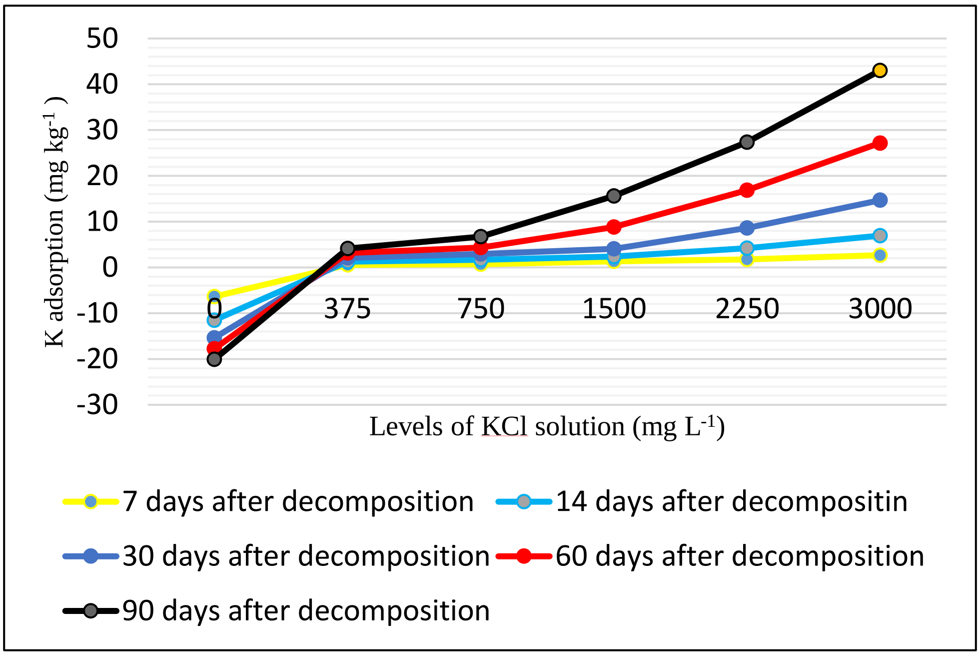


Fig 5. Magnitude of potassium adsorption on plantain compost (mg kg^{-1})

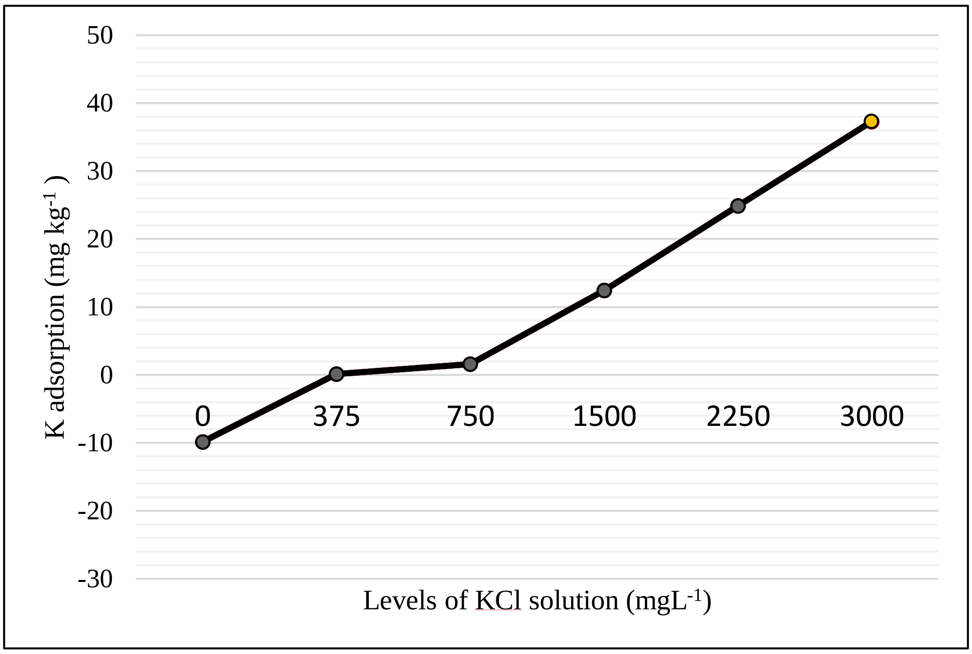


Fig.6 Adsorption curve of rice straw (at different decomposition intervals) and plantain compost

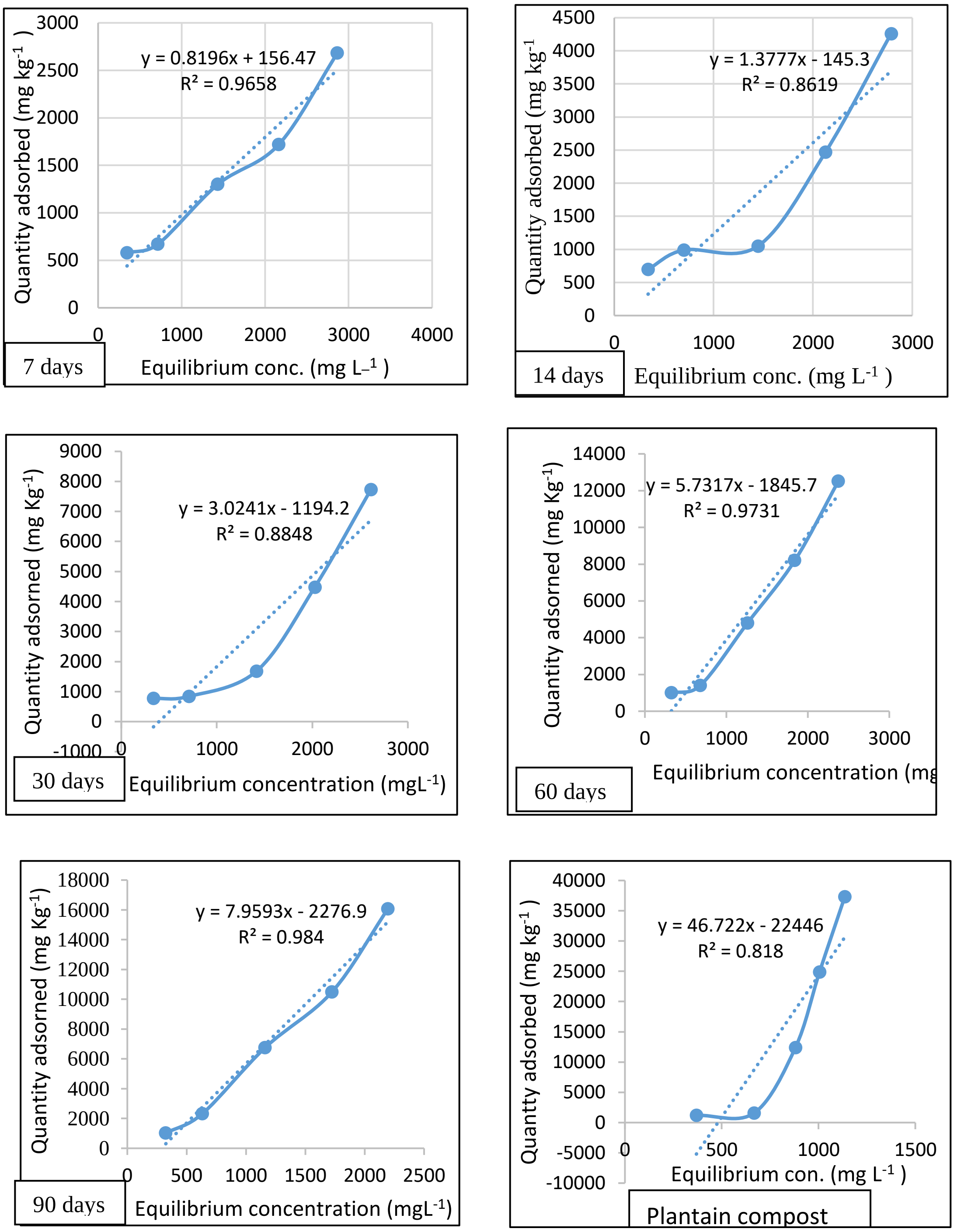


Fig 7. Freundlich adsorption isotherm of rice straw (at different decomposition periods) and plantain compost

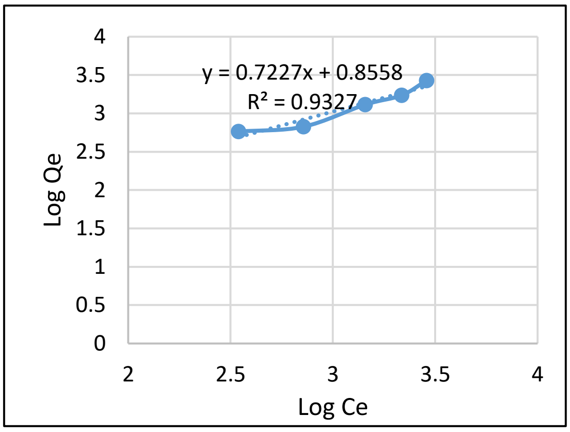


Figure 1(After 7 days)

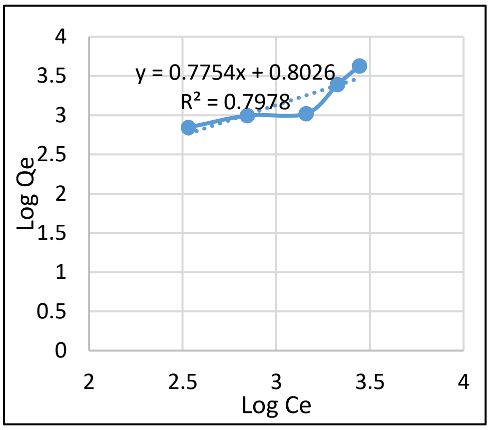


Figure 2 (After 14 days)

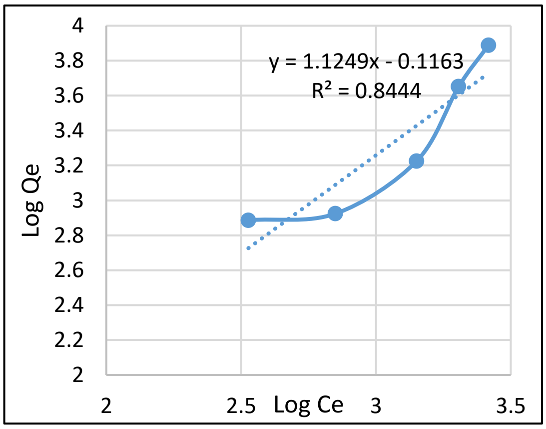


Figure 3 (After 30 days)

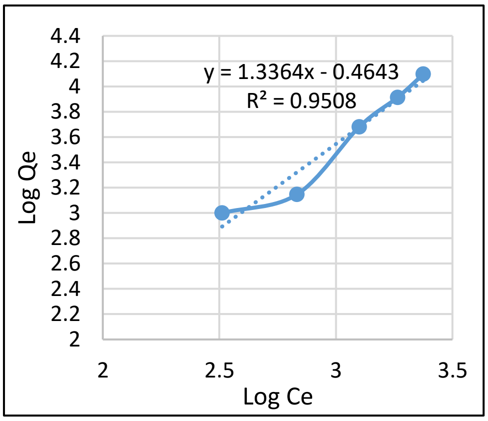


Figure 4(After 60 days)

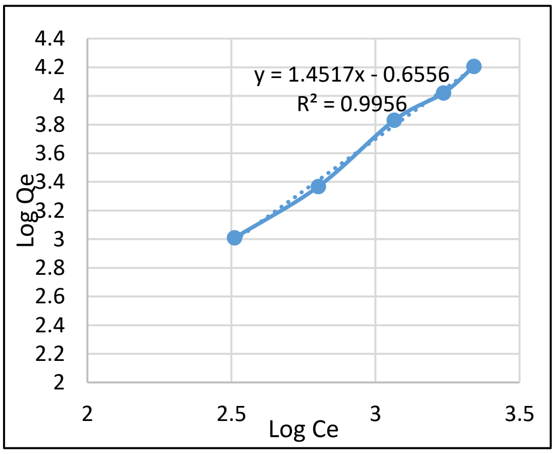


Figure 5 (After 90 days)

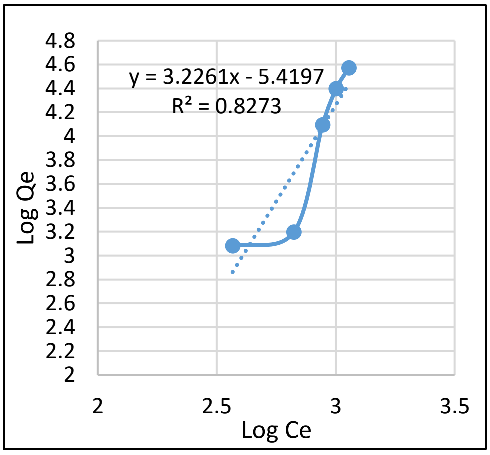


Figure 5 (Plantain compost)

Experiment 3. Incubation study

5.3.1 Physico-chemical properties of soil

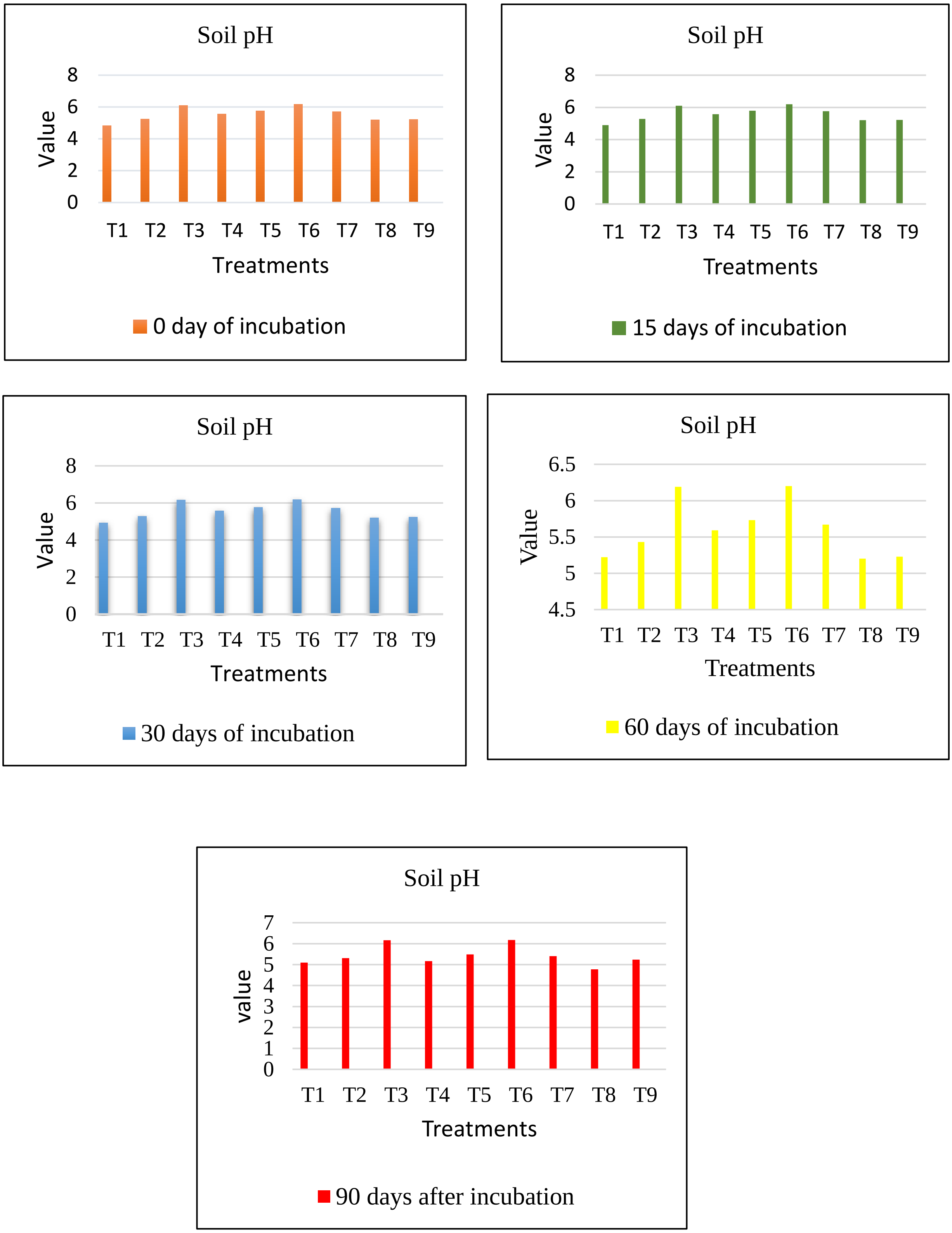
The trend in the values of physico-chemical properties of soil during 0 and 90 days after incubation are discussed below.

5.3.1.1 Soil pH

The data pertaining to soil pH after incubation experiment among all the treated soils showed slightly acidic pH value under different intervals (Fig. 8).The pH value among different intervals in the control treatment showed a mean value of 5.23. Normally, the pH of lateritic soils comes under the range of 4.5 to 5.5due to high rainfall (>3500mm) and intense leaching of bases (Chandran*et al*, 2005).

The lower pH value among the treatments containing rice straw was due to its slightly acidic pH of 5.8 compared with other organic K rich sources. The higher pH value in treatments containing wood ash with FYM and potash (T3) and wood ash with FYM alone with lime and potash (T6) were due to the presence of wood ashwhich generally have pH between 8.9 to 13.5 (Demeyer *et al.*, 2001). This increase in pH among wood ash treated soil was mainly due to ligand exchange between wood ash SO_4^{2-} and OH^- ions (Alva and Summer,1990) and the presence of Ca compounds that are less soluble which maintains the alkalinity of the material even at small quantity in soil. Limed treatments were having comparatively higher pH than non-limed treatments. Towards the end of incubation period, soil pH has decreased as stated by Erich and Hoskins (2011) due to drying effect.

Fig 8. Soil pH under different incubation intervals



5.3.1.2 Electrical conductivity

The change in electrical conductivity was more or less constant (Fig. 9). The reason for the constant value might be due to low concentration of salts in lateritic soils. Among different treatments the very slight changes in the EC value at 0 and 90 days after incubation was in T6 treatment (Wood ash with FYM +lime +potash) was mainly due to increased concentration of salts such as, Ca, Mg, SO_4 along with lime treatment. Similar findings were registered from the study conducted by Nkana *et al.*(2002).

5.3.1.3 Soil organic carbon

All the treatments showed higher range in the value of SOC (>1.5%). The value has decreased from 0 to 90 days under all treatments due to degradation of added organic residues and the better utilization of carbon (Fig. 10). Among all treatments the highest value of SOC was observed in T1 treatment(RS+K) because a higher content of carbon was analysed in rice straw (53.20%) than plantain compost (28.24%). Eagle *et al.* (2000) from his study also observed that application of rice straw enhanced SOC and other nutrients in the soil. Because, its application has significantly increased SOC mainly due to higher content of carbon in rice straw (Surekha *et al.,* 2004). The application of rice straw in situ has contributed towards recycling of nutrients, increase in SOC and yield of subsequent crops (Gupta *et al.,* 2007).

Application of lime also has an effect on soil structure which in turn affects SOC mineralization. Lal (2005) stated that improved soil structure and aggregate stability that has been formed by the application of lime has enhanced the potential for the physical protection of SOC within the aggregates and also reduced its susceptibility to mineralization by microbes. Liao *et al*. (2013) from their findings revealed that application of rice straw could enhance the initial status of SOC by 21 percentages.Comparing with limed and non-lime treatments, SOC mineralization was lower in short term applied limed soils due to stabilizing effect of Ca^{2+} present in the lime (Grover *et al.,* 2017).

Fig 9. Electrical Conductivity of soil with different treatments

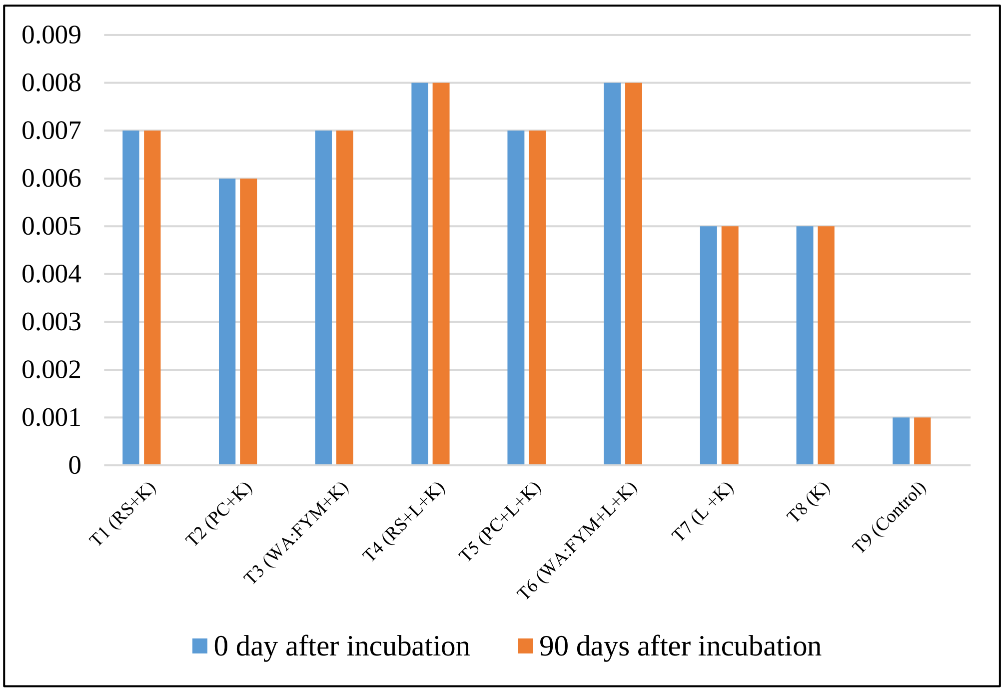
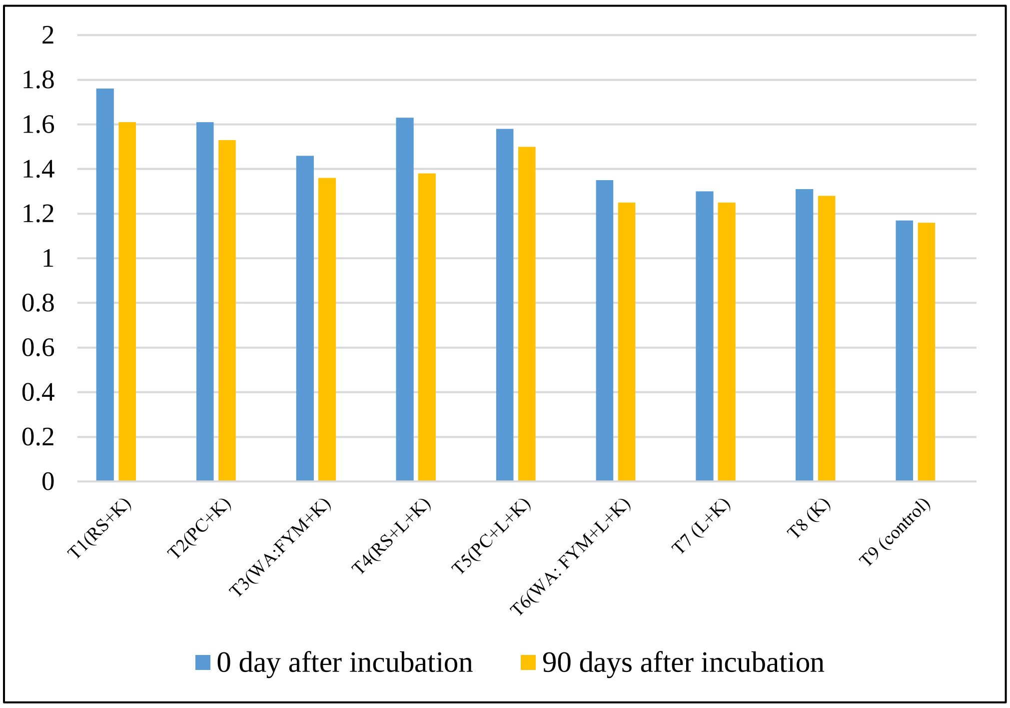


Fig 10. Soil organic carbon (%) under different treatments



5.3.1.4 Available nitrogen

The value of available N content has decreased in all treatments from 0 to 90 days after incubation (Fig. 11). But among the treatments, the highest value in T4 treatment (Rice straw + lime+ potash) might be due to greater rate of N mineralization in rice straw and its slow decomposition rate compared to plantain compost and wood ash. The value of C/N ratio is usually used to explain the factors that determines the decomposition rate of crop residues (Cheshire and Chapman, 1996). Application of rice straw enhances soil microbial interaction and N mineralization (Singh, 1995). Studies have also indicated that incorporation of rice straw has increased the plant available N in the soil. It contains easily decomposable carbon and has lower C/N ratio (70:1) compared with FYM (100:1) that determines the N dynamics in soil resulting in mineralization (Takahashi *et al.*, 2003).

5.3.1.5 Available phosphorous

The value has slightly decreased among all treatments from 0 to 90 days after incubation might be due to fixation and complex formation by Kaolinitic type of clay mineral present in the lateritic soil. Among different treatments, T3 (Wood ash with FYM + potash) reported the high value both at 0 and 90 days after incubation (Fig. 12).Ohno and Erich (1994) also observed similar findings regarding the availability of P due to wood ash application. In acidic soils like lateritic soils, P present in the wood ash would become immobilized through complex formation with Fe or Al under long term incubation (Demeyer *et al.,* 2001). From the study conducted by Jansone *et al.* (2020) it was registered that application of wood ash has increased the P content two to three times than the control plot because, wood ash contains 0.3 % to 1.4 % readily available P which are easily adsorbed on the soil surface soon after its application.

Fig 11. Available nitrogen (mg kg^{-1}) under different treatments

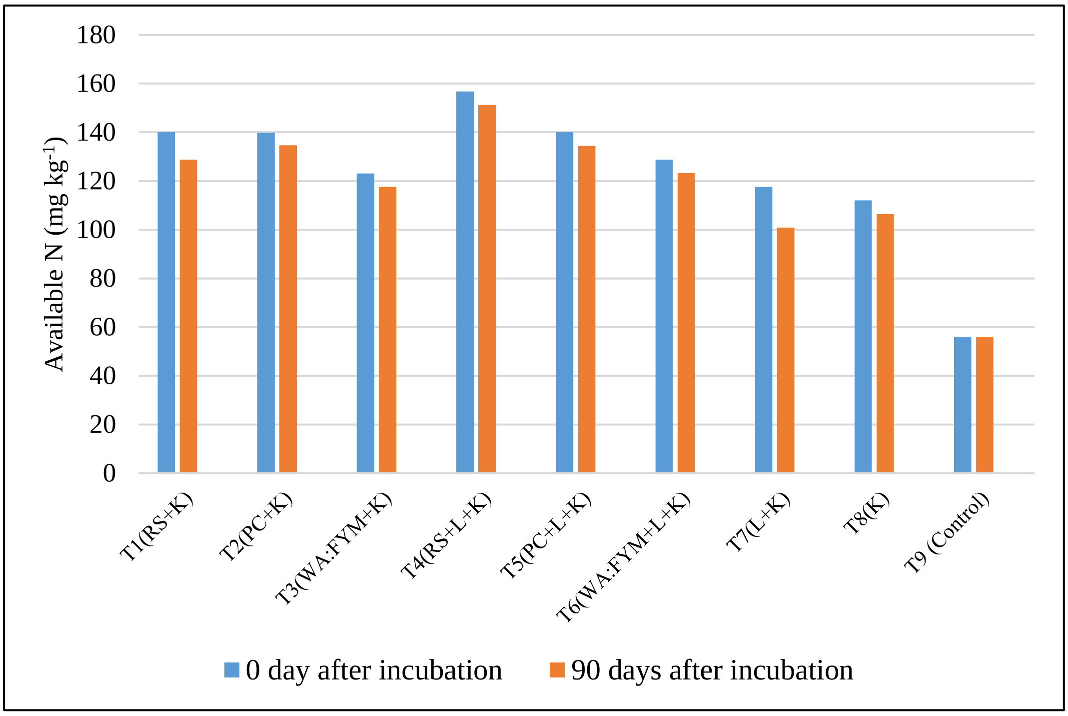
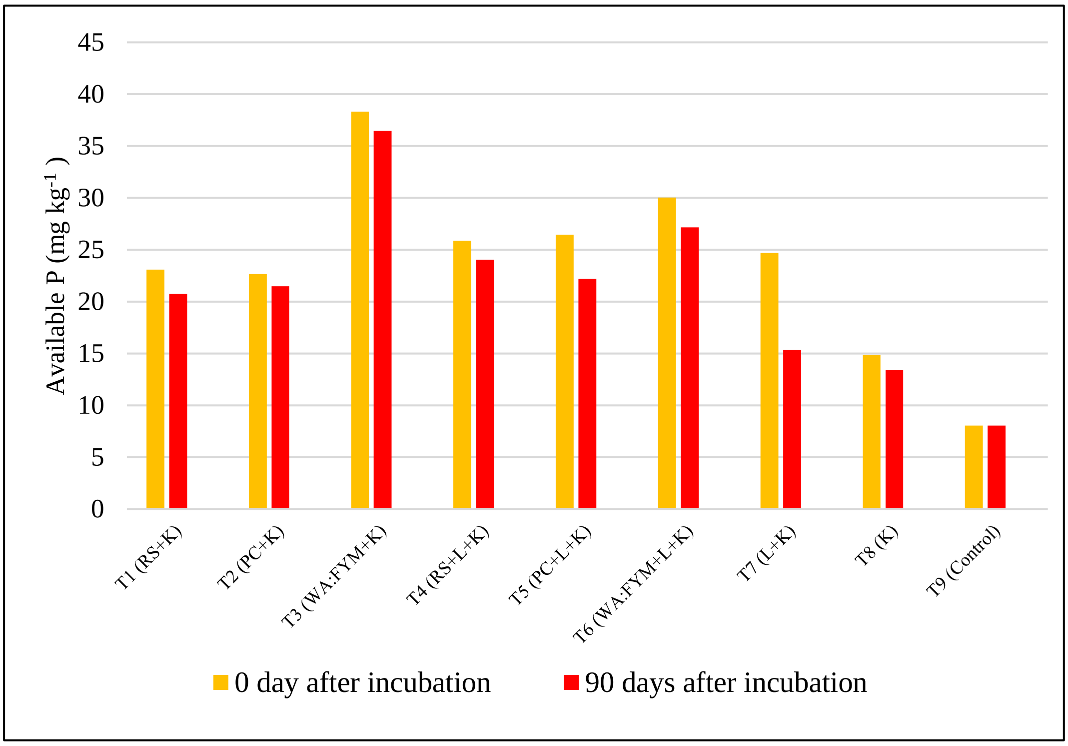


Fig 12. Available Phosphorous (mg kg^{-1}) under different treatment



5.3.1.6 Available calcium

The value of Ca increased in all treatments from 0 to 90 days except for control treatment (Fig. 13). The Ca content was under sufficient category under all treatments (>300 mg kg^{-1}) except for T8 (potash) and T9 (control treatment). The higher value in T6 treatment (Wood ash with FYM+lime+potash) both during 0 and 90 days after incubation was mainly due to presence of wood ash along with lime. Calcium is the most abundant element in the wood ash (7%-33%) and gives the ash properties similar to that of agricultural lime. The findings of Lerner and Utzinger (1986) revealed that residential wood ash has CCE value that ranged from 83 to 116 % depending upon the species burned.

5.3.1.7 Available magnesium

The Mg content among different treatments increased from 0 to 90 days after incubation (Fig. 14). The content was under sufficient category (>120 mg kg^{-1}) except for T7 (lime), T8 (potash) and T9 (absolute control) treatments. Similar to that of Ca content, treatment with wood ash-FYM with lime and potash (T6) showed the highest Mg content. The content of Mg is higher in wood ash (1.01%) and FYM (0.76%) compared to rice straw and plantain compost. There are some studies that have even observedthat application of wood ash had enhanced the base saturation and amount of exchangeable bases like Ca^{2+} and Mg^{2+} (Nkana *et al.*, 1998).

Fig 13. Available calcium (mg kg^{-1}) under different treatments

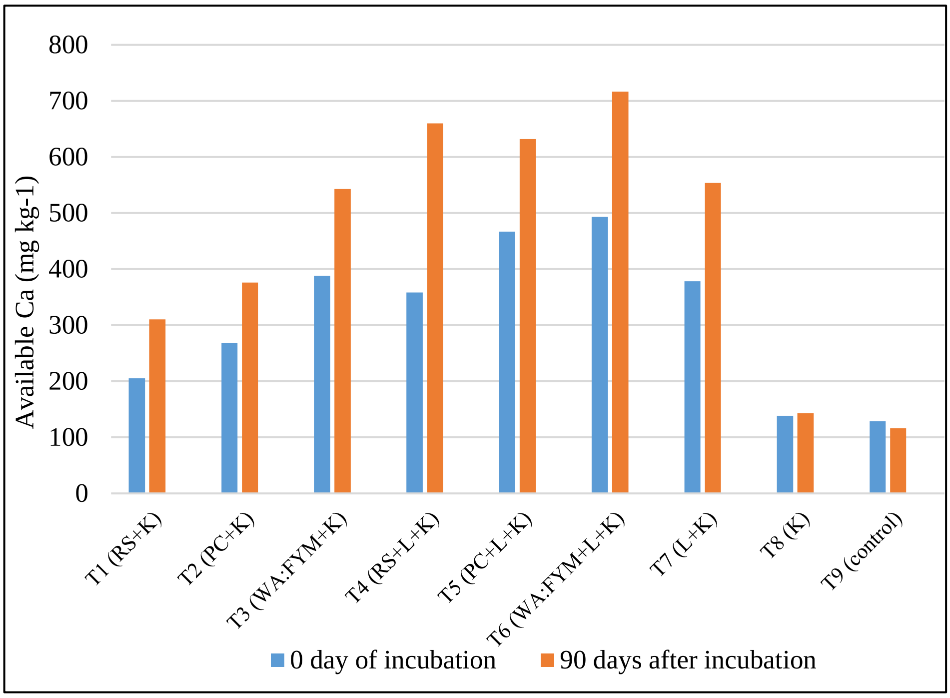
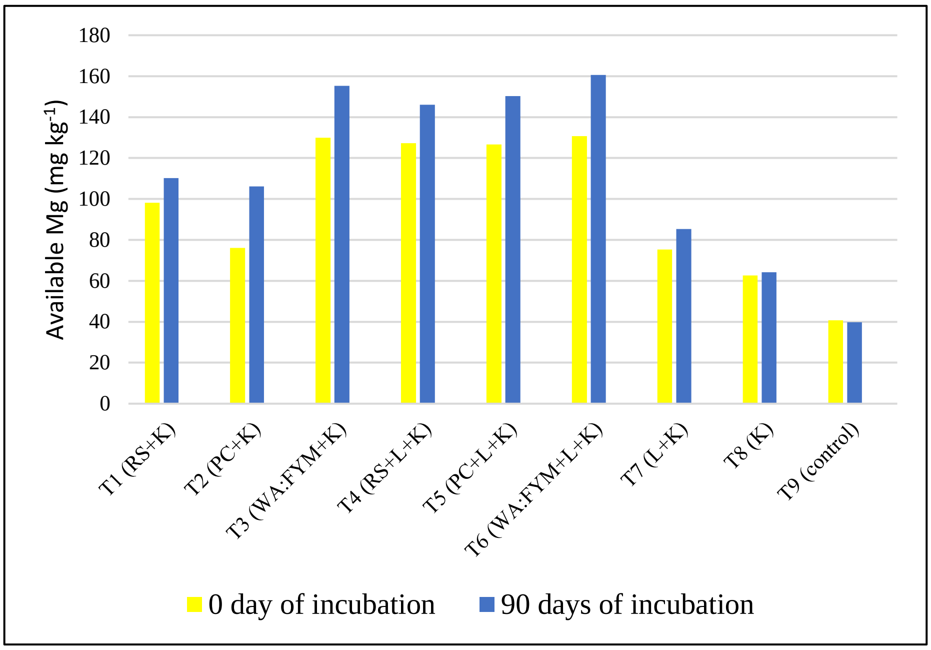


Fig 14. Available magnesium (mg kg^{-1}) under different treatments



5.3.1.8 Available sulphur

The data on available S showed that S content decreased in all treatments from 0 to 90 days after incubation (Fig. 15). The reason is that sulphur is relatively immobile in soil and is leached as sulphate ion and also by oxidation in the sulphur cycle in the soil. The highest value was observed in T6 treatment (wood ash with FYM + lime+ potash). Application of FYM has resulted in improving soil physico-chemical properties along with the direct release of macro and micro nutrients that are easily available for plants (Lakkineni and Abrol, 1994). The N/S ratio of FYM is about 1:0.15. Furthermore, the mineralisation of S from organic resources depends on the C/N ratio of the material. Farm yard manure with C/S ratio between 430 and 735 was found to have mineralized organic sulphur to sulphate at the rate of 47 % and 127 % respectively (Tabatabai and Chae, 1991).

5.3.1.9 Available iron

In all the treatments except control, the content of available Fe in the soils had increased with the advancement of period of incubation (Fig. 16). Thehighest value of available iron was observedin the treatment containing plantain compost with lime and potash (T5) during 0 day and 90 days after incubation. The reason might be due to higher content of iron in plantain compost (0.3%) that were easily mineralized in soil. Normally laterite soils are rich in sesquioxides like iron and aluminium that are derived from a wide variety of rocks by weathering under strong oxidizing and leaching condition. Since the pH of soil is under acidic condition under T5 treatment, it is more favorable for the mineralization of iron rich mineral compounds in the soil and the application of compost prepared by vermi technology would have enhanced the mineralization of sesquioxides by maintaining their pH.

Fig 15. Available sulphur (mg kg^{-1}) under different treatments

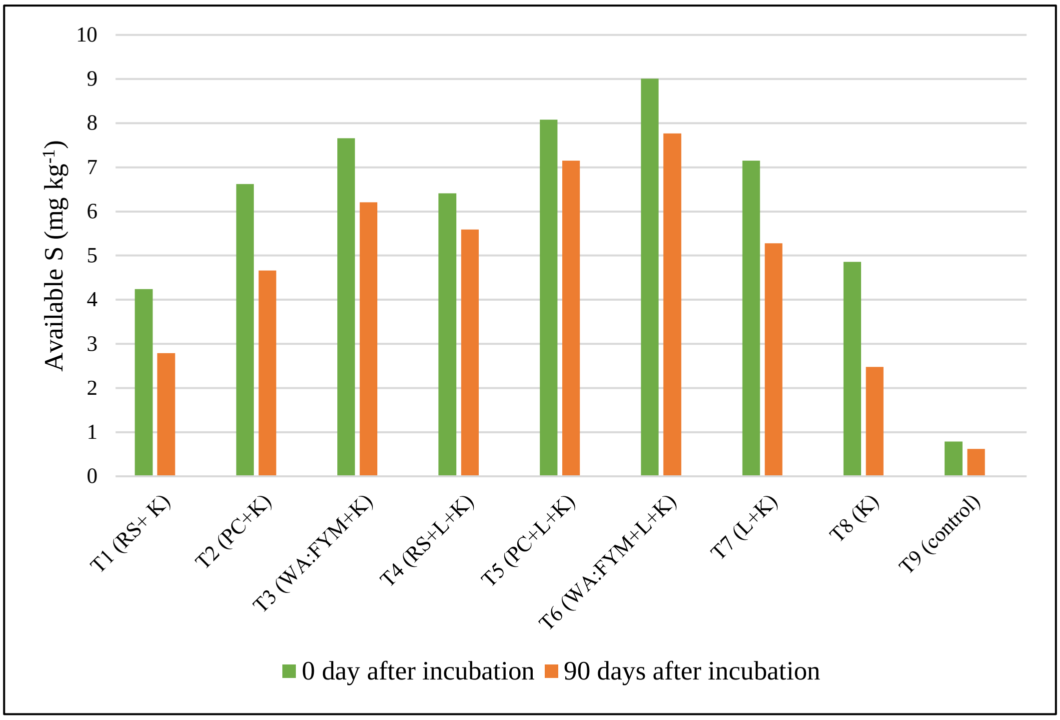
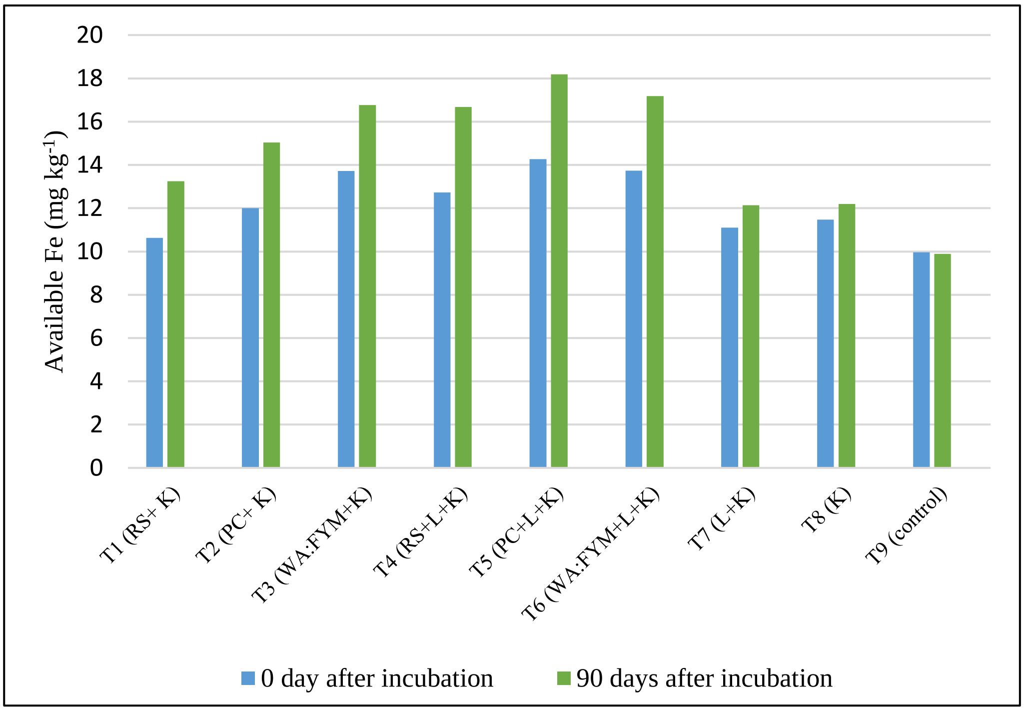


Fig 16. Available iron (mg kg^{-1}) in the soil samples under different treatments



5.3.4.10 Available manganese

The value among all treatments showed an increase in value from 0 to 90 days after incubation except in T9 (absolute control) (Fig. 17). The highest value was noticed in treatment containing rice straw with lime and potash (T4) both at initial and final days after incubation. The study showed slightly higher value for Mn in rice straw (0.24%) compared to other resources.Incorporation of rice straw can form dissolved organic matter in the soil and it compete with the heavy metal for the adsorption site. The most abundant metal present in rice straw is silicon which has an antagonistic effect with manganese. As heavy metals like Si compete for the adsorption sites, it enhances the dissolution of manganese thus increasing its mobility in soil (Jin*et al.,* 2020).

5.3.4.11 Available copper

The data on available Cu showed an increment in the value from 0 to 90 days after incubation except in T9 (absolute control) treatment (Fig. 18). The highest value in T5 treatment (plantain compost+ lime+ potash) both at 0 and 90 days after incubation was due to high content of Cu present in plantain compost (0.04%) than rice straw (0.003%). Similar findings were also noticed by Doran and Kavya (2005) while experimenting on compost made using banana waste.

Fig 17. Manganese (mg kg^{-1}) content in the soil samples under different treatments

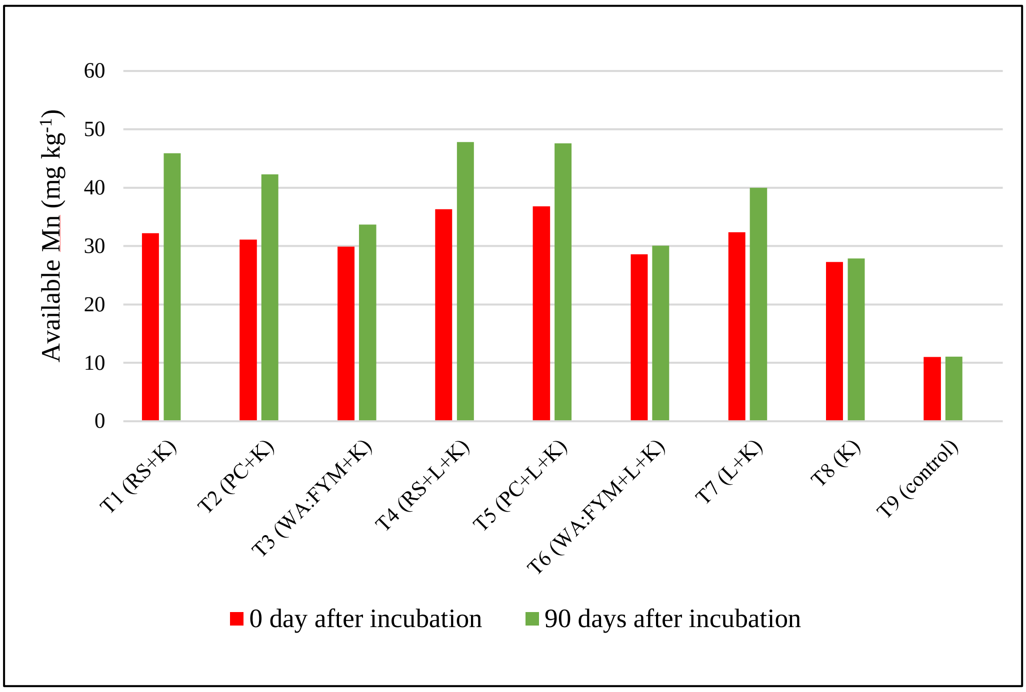
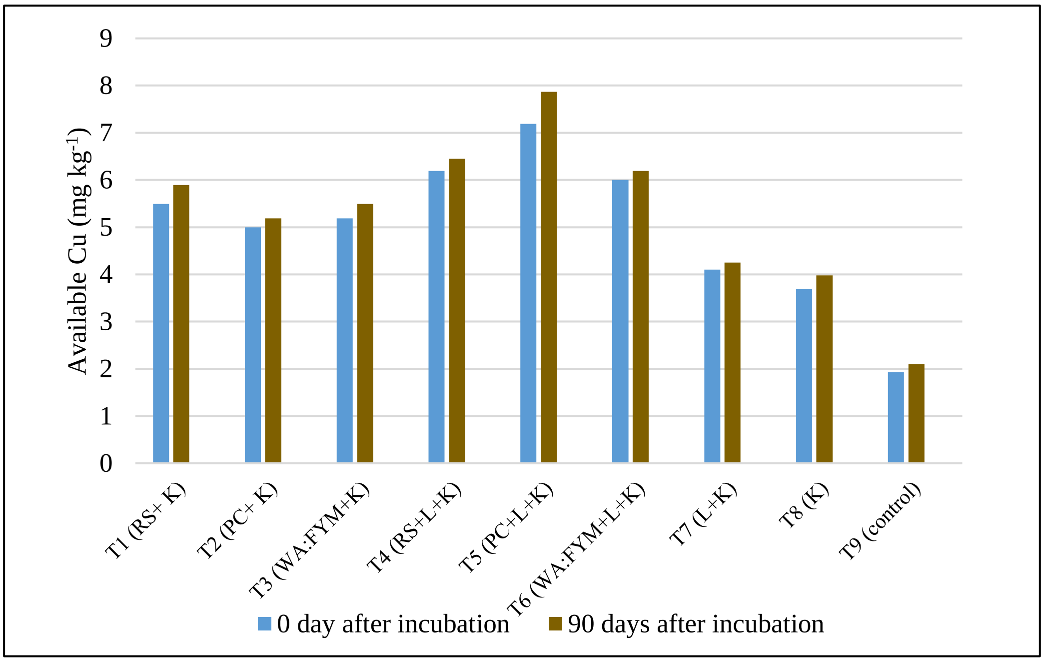


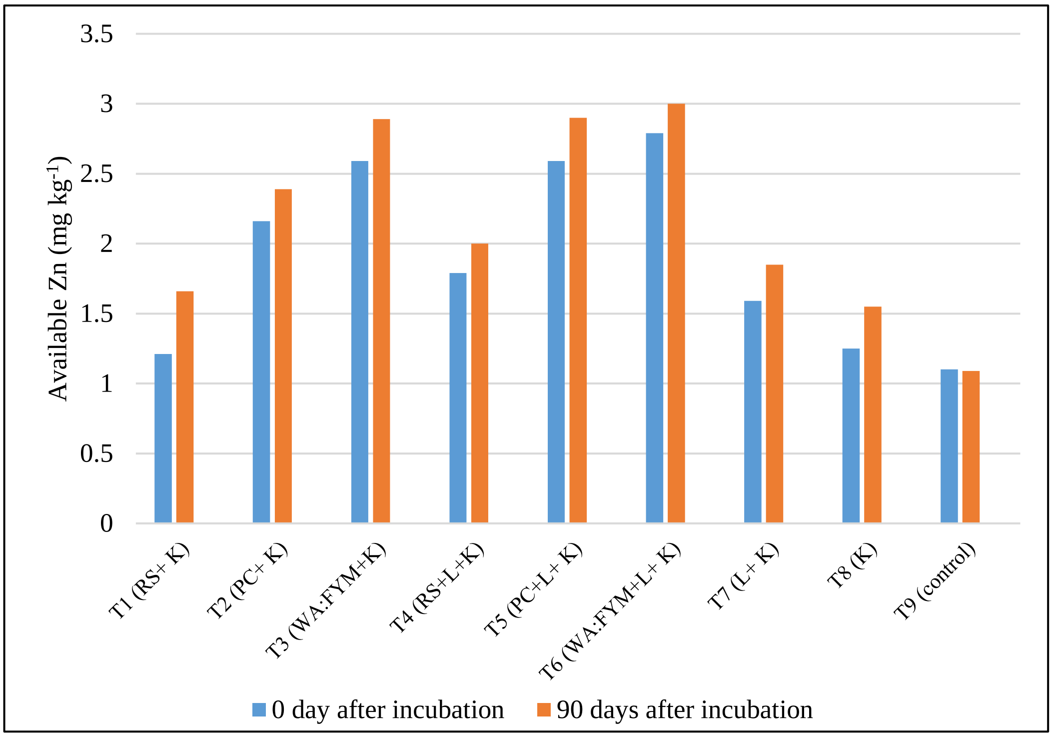
Fig 18. Available copper (mg kg^{-1}) content in the soil samples under different treatments



5.3.4.12 Available zinc

The data on available zinc content showed an increase in the value except for T8 (potash) and T9 (absolute control) treatments (Fig. 19). This might be due to antagonistic effect of phosphorous with zinc as forming insoluble compounds like $Zn_3(PO4)_2$ thus resulting in the lower quantity of P in available pool (Das *et al.*, 2005). The highest value both at 0 and 90 days after incubation was in T6 (wood ash with FYM+lime +potash) which was due to higher content of zinc present in wood ash. Jansone*et al.*(2020)also indicated higher Zn content in wood ash (35 ppm to 233 ppm). At the same time FYM was found to enhance the mineralization of Zn content thus increased its availability in soil.

Fig 19. Available Zinc (mg kg^{-1}) content in the soil samples under different incubation intervals



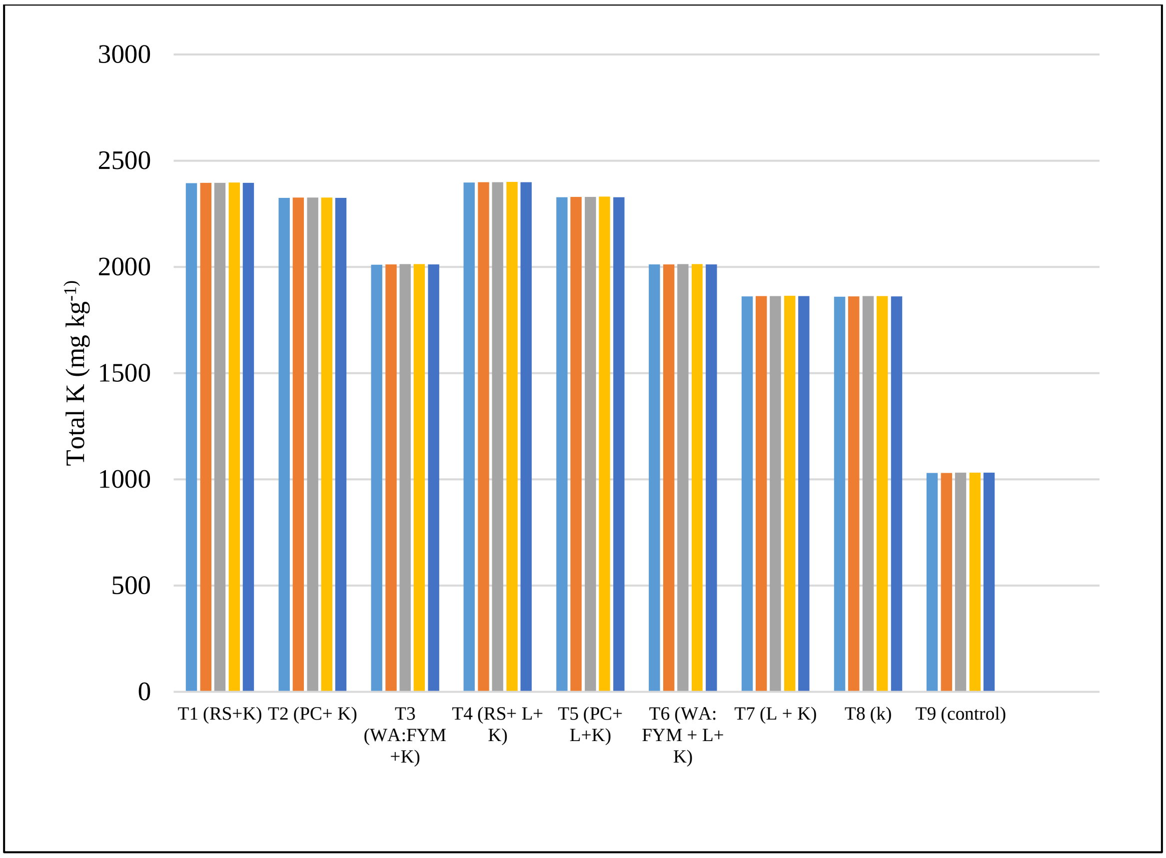
5.2 Different forms of potassium

The comparison of different fractions of potassium from different treatments under different incubation intervals has been discussed below.

5.2.1 Total potassium

The observed data depicts that the value of total K from all the treatments had increased up to 60 days which was later followed by a decrease after 90 days of incubation (except for control treatment) (Fig. 20). It might be dueto increase in the concentration of available forms of K that has resulted in a total increase of K. Kaurand Benipal (2006) also revealed similar findings in their study on various forms of K treated soil with incorporation of organic resources under incubation.Singh and Wanjari (2012) has also noticed the increase in total K value under soil amended with rice straw or other organic sourceswhich can be attributed to addition of K through organic sources that has increased the content of total K in the soil. The higher value of total K in the rice straw combined with lime and MOP (T4) treated soil was due to slow conversion of total K to other forms as the decomposition prevails. At the same time, rice straw contains more amount of reserve K than other organic sources and application of lime has increased the fixation of reserve K.The amount of total K is more pronounced in the subsurface than surface because of the high mobility of K^+ it has a tendency to leach towards the subsurface. Total K content in soil did not have any remarkable significant relation with soil properties (Singh,2016).

Fig 20. Total K (mg kg^{-1}) content in the soil samples under different treatments



5.2.2 Exchangeable potassium

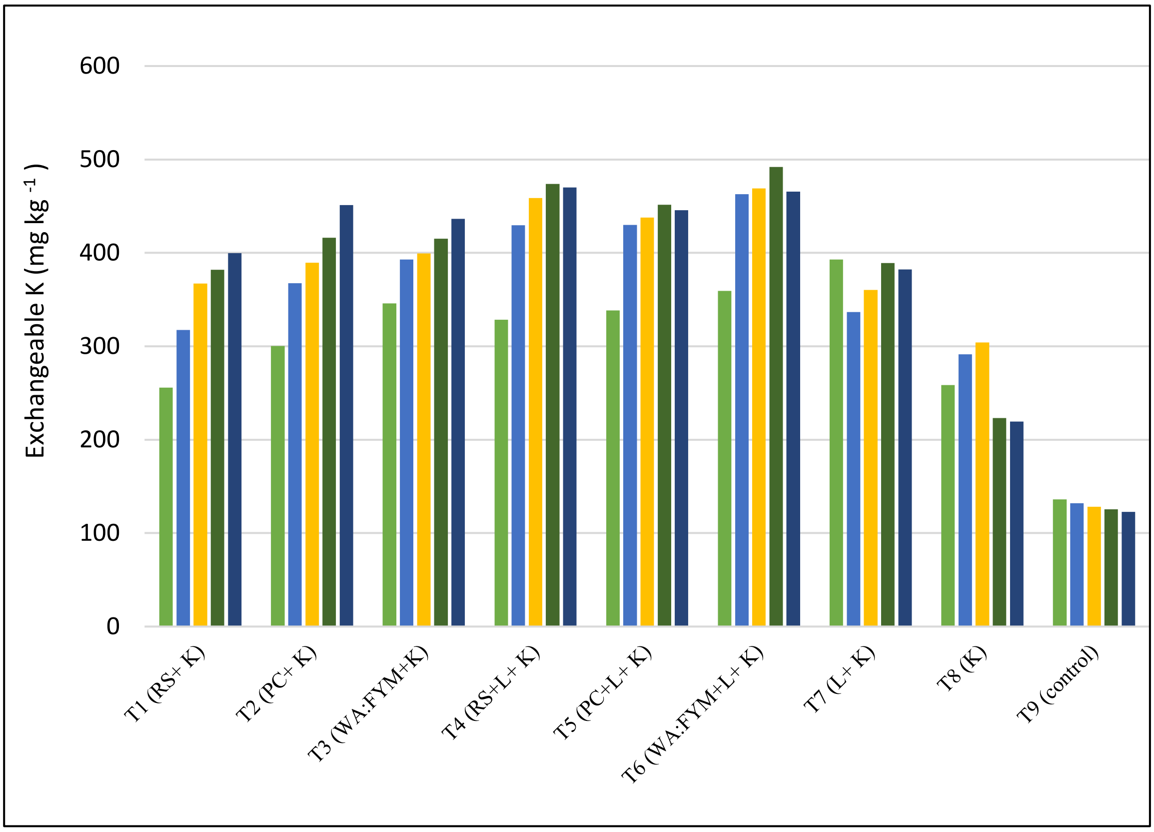
The non-limed treatments showed an increase in the exchangeable K from 0 to 90 days after incubation (Fig. 21). But in the case of limed treatments, the value increased upto 60 days followed by a decline after 90 days of incubation. The levels of exchangeable K in the soil also depends on the level of lime application. Das and Saha (2014) have noticed that fully limed soils have more exchangeable K than partially limed soil. Because higher doses of Ca^{2+} occupy the exchangeable site which enhances the release of non-exchangeable K in the exchange phase.But the decrease after 60 days of incubation is due to the action of Ca^{2+} in the system that aids the conversion of exchangeable K^{+} to non-exchangeable or mineral form.

Ganai*et al.* (2013) had observed an increase in the water soluble K, exchangeable K and decrease in non-exchangeable and total K in rice-wheat system grown on alluvial soils under varying nutrient management for about 15 years. The application of rice straw has retained the exchangeable form of K for long term compared to other treatments. The study showed a higher value of exchangeable K under rice straw with lime and potash (T4). Yadav *et al.* (2018) found that the incorporation of rice straw has enhanced the exchangeable K by 98.6 % and 47.5 % respectively over inorganic fertilizers and FYM treated plots.

Sharpley (1989), had observed that solubility of exchangeable K increased from smectitic to kaolinitic soils. Hencekaolinitic soils were more depleted of their exchangeable K compared to smectitic soils. Exchangeable K determines easily available K but it fails to determine long term ability of soil to release potassium (Cervantes and Hanson, 1991).

Rani *et al.* (2020) from their studies indicated that the addition of organic sources increases the CEC of soil and organic colloids which likely caused greater adsorption of exchangeable K by conversion of unavailable forms to available forms as a result of mass effect.

.Fig 21. Exchangeable K (mg kg^{-1}) under different treatments



5.2.3 Non exchangeable potassium

Results showed that the amount of non-exchangeable K had increased up to 60 days followed by decrease towards 90 days after incubation (Fig. 22). This is because saturation of exchangeable complex with K has led the excess K^+ ions to the wedge and interlayer spaces that has resulted in the fixation of a part of exchangeable form to non-exchangeable form. At the same time, limed treatments have comparatively more amount of non-exchangeable K than un-limed treatments which is mainly due to the precipitation of hydroxyl aluminum and iron polymers that have restricted the release of non-exchangeable K (Das and Saha, 2014). At the same time liming causes the expansion and weathering of lattice of clay minerals which simplifies the release of lattice K in the soil.

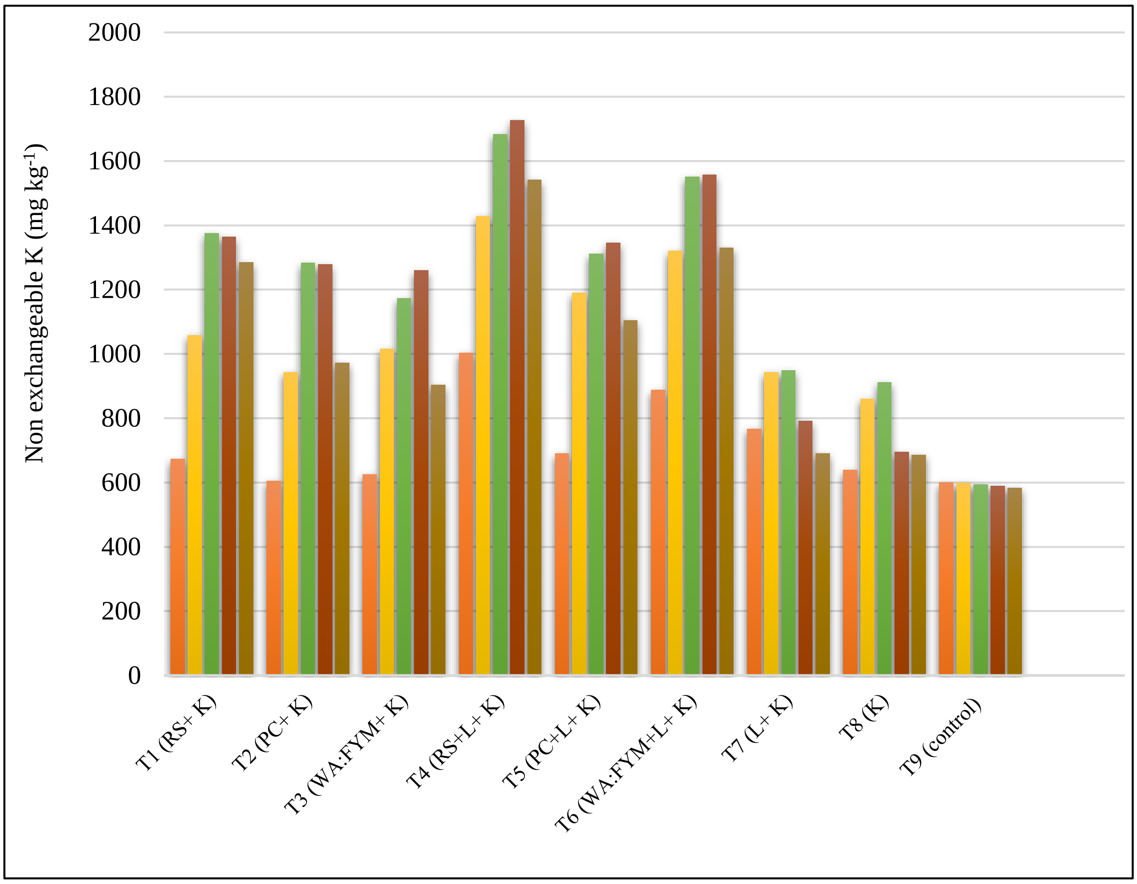
Some studies explain that the release of non-exchangeable fraction of K occur when the available forms decreased by crop removal or by leaching (Sarkar *et al.*, 2013).Therefore, analysis of both available K and non-exchangeable K characteristics must be done while determining availability of soil K and its exogenous efficiency especially under long term system.

The higher final value of non- exchangeable K in the treatment containing rice straw with lime and potash might be due to more inter planar sites in the material that trap the K^+ ions into fixed form and since the material is not completely decomposed, there is a chance of slow release of K^+ ions from these inter planar sites. Application of lime generally increase the fixed form of K especially under acidic soil (Ghosh and Mukhopadhyay, 2001)

Martin and Sparks (1985) indicated that the amount and rate of release of non-exchangeable form mainly depends on the amount of potassium in soil solution along with the type and quantity of clay minerals present.The reserves of non-exchangeable K are more in temperate regions compared to tropical areas mainly due to the presence of 2:1 type of illite clay minerals that has greater capacity to fix K^+ on non-exchangeable sites (Sharma et al., 2010).

Johnson and Mitchell (1974) noticed that those soils having higher amount of exchangeable K also had higher concentration of non-exchangeable K and the rate of release of K from non-exchangeable pool was linearly related to the amount of exchangeable K. Therefore, higher amount of non-exchangeable K is a good indicator for long term K supply.

Fig 22. Non- Exchangeable K (mg kg^{-1}) under different treatments



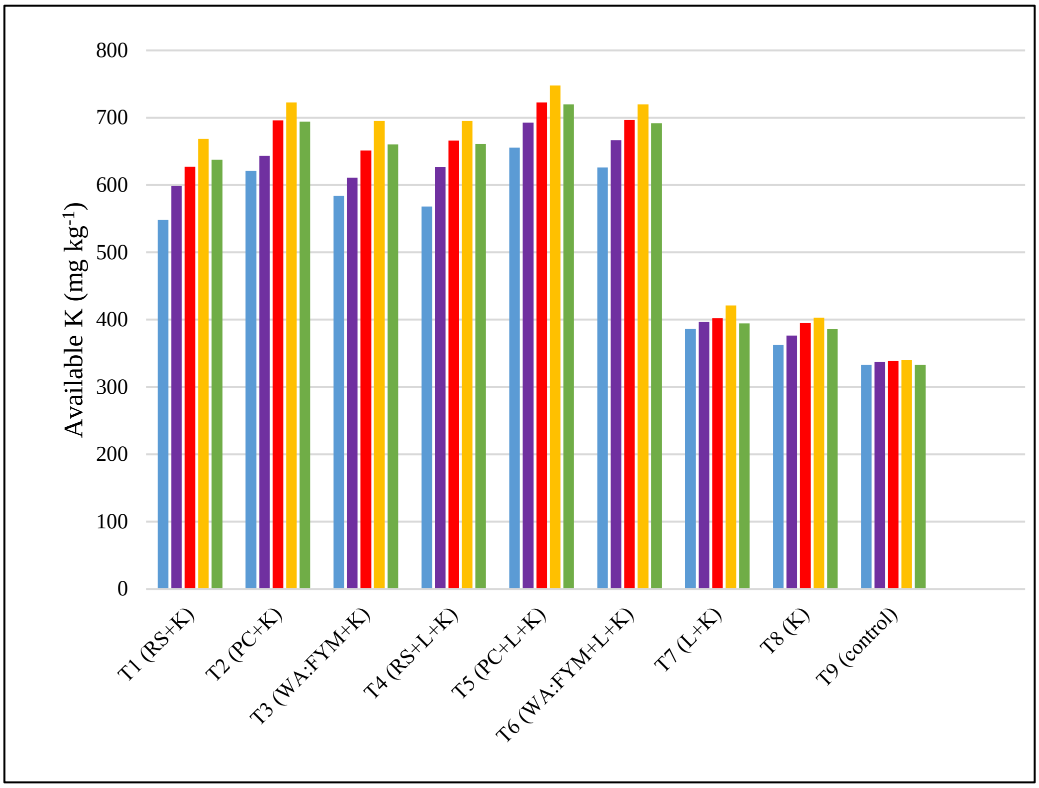
5.2.4 Available potassium

The results showed that addition of plantain compost with lime and potash (T5) has the higher concentration of available form followed by rice straw and wood ash with FYM combination along with lime and potash (T4 and T5) in long term (fig. 23). It is noticed that long term incorporation of decomposed organic manure either alone or in combination with any inorganic fertilizers will enhance the available K in Ultisols and Alfisols of India (Srinivasarao*et al.*, 2010).

Theoretically, soils with greater quantity of organic matter supply a large number of adsorption sites for exchangeable K thus protecting the available K against fixation. But it is also observed that addition of organic carbon to the soil may also result in immobilization of available nutrients by altering the physical, chemical and biological factors in the soil under long time incubation. (Zhang *et al.*, 2017). So the presence of organic sources in the treatments might have caused the decline in the available K forms after 90 days of incubation.

Bear (1976) observed that with increased incubation period, K mineralization also increased remarkably and enhanced the available K pool in the soil by the release of more organically bound potassium in the soil eventually by the decomposition of organic matter. Increase in the available K not only due to enrichment with K resources (Dhanorkar*et al*., 1994). Apart from this, native K has also become more available due to action of organic acids released during decomposition of organic matter. Brar*et al* (1998) has also revealed that those soils treated with organic manure has higher release of available K than unmanured soil and the rate of release also get higher under the treatment including the combination of organic sources with inorganic materials. That might be the reason why available K release was maximum under those treatments having combination of organic sources with lime and potash than with organic sources and potash.

Fig 23. Available K (mg kg^{-1}) under different treatments

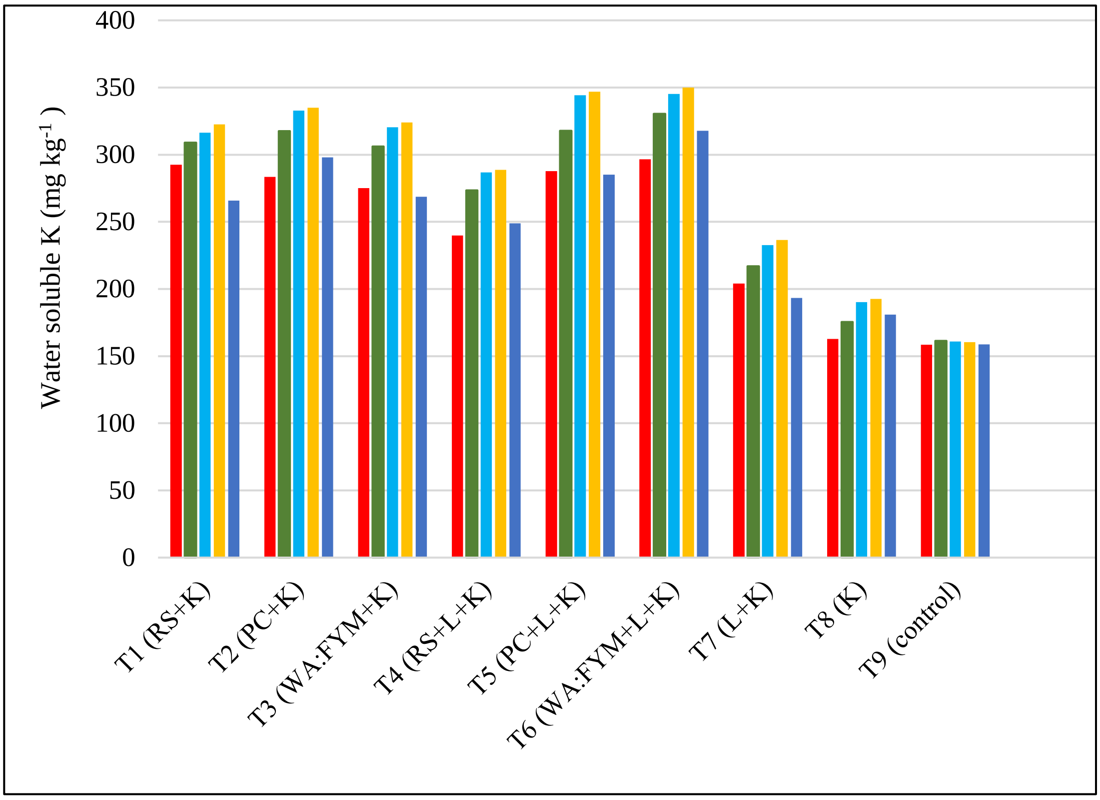


5.2.5 Water soluble potassium

The analysis on water soluble K under different treatments indicated that the application of wood ash with FYM, lime and potash showed the maximum release (Fig. 24). It is due to presence of highly soluble potassium in wood ash. The presence of FYM has greatly enhanced the solubility of potassium in soil through mineralization. Singh *et al.* (2001) explained that the impact of application of FYM increases the availability of water soluble K that may be assaigned to the direct addition of K to the soil, reduction in K fixation and solubilisation and also due to release of K by the interaction of organic matter with clay. The addition of FYM is a good source of both potassium and nitrogen content. So the NH_4^+ released from FYM competes with the water soluble K^+ thereby reduce the K fixation and increase the amount of water soluble K in the soil (Du *et al.,* 2007). The presence of Ca^{2+} in the lime has replaced the exchangeable K from its exchange phase thus increasing the level of water soluble K in the soil.

Yadav *et al.* (2018) also noticed that those plots treated with FYM showed remarkably higher concentration of water soluble K by 41.40% compared to inorganically treated plots. But the rate of release showed a decrease after 90 days mainly due to exhaustion of the soluble potassium that has slowly resulted in fixation with clay minerals other than humus present. Reports have shown that organic manure has a great ability to form metallo-organic complexes of high solubility. Later, the decomposition of organic matter present in the organic material produces some organic acids which causes the dissolution of non-exchangeable K thus converting them into available forms (Rani *et al.,* 2020). This might be the reason why the treatment of wood ash with FYM combination along with lime and potash resulted in the maximum release of water soluble K in the soil.

Fig 24. Water soluble K (mg kg^{-1}) under different treatments



Summary

6. SUMMARY

The present study entitiled “Utilisation of potassium rich crop residues for retention of potassium in lateritic soil” was conducted in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellanikkara during the year 2020-21 with three experiments.

The first experiment constituted of physico-chemical characterization of rice straw and plantain compost, decomposition dynamics of rice straw and the rate of K release from rice straw at different stages of decomposition.

The second experiment consisted of an adsorptiuon study to determine the extent of adsorption of K from the solution by rice straw and plantain compost.

The third experiment was an incubation study to assess the capacity of different organic K resources to retain and release K in lateritic soil.

Studies of characterization of rice straw and plantain compost revealed that rice straw had higher content of K (1.53%) than plantain compost (1.33%).

The pH of the rice straw was very much lower (5.8) than that of plantain compost (9.3).

Total carbon content of rice straw (53.20%) was very much higher than plantain compost (28.24%).

Comparatively higher content of total carbon (53.20%), nitrogen, (0.76%), potassium (1.53%) and manganese (0.24%) was noticed in rice strawthan plantain compost.

However, P content was very much higher in plantain compost (1.04%) compared to rice straw (0.76%). The contents of Ca, Mg, Fe, Cu and Zn were comparatively higher in plantain compost than that of rice straw.

Studies on decomposition dynamics of rice straw revealed that rice straw decomposed to an extent of 51.90 % within a period of 90 days. The K release rate from rice straw was 84.28 % by 90 days after incubation.

Adsorption studies with rice straw and plantain compost indicated that increased concentration of KCl solution resulted in higher adsorption of K by both rice straw and plantain compost. On comparing the K adsorption by rice straw and plantain compost, it was found that rice straw had a capacity to adsorb 16.08 mg of K per gram of the material whereas in the case of plantain compost, the magnitude of adsorption of K was 37.29 mg K per gram of the material. The differences in the magnitude of adsorption could be attributed to the variation in the particle size of rice straw (>0.5mm) and plantain compost (<0.2mm).

The salient features of the incubation study conducted in the lateritic soils at different incubation intervals are furnished below:

- Significantly higher pH value was observed under the T6 treatment (Wood ash with FYM, lime and MOP) throughout the period of incubation. There was an increasing trend in the pH of soil samples under different treatments from 0 to 60 days after incubation which was followed by a decline after 90 days of incubation.
- The organic carbon, available nitrogen, available phosphorous and available sulphur content of the soil samples showed a decline in all the treatments towards the later periods of incubation.
- Organic carbon content in the treatment containing rice straw with MOP (T1) showed higher values (1.76% and 1.61 %) at 0 and 90 days after incubation.
- Available nitrogen content was significantly higher in the treatment containing rice straw with lime and MOP (T4) with values of 156.80 mg $kg^{-1}$and 151.19 mg kg^{-1} at 0 and 90 days after incubation.
- The treatments with wood ash with FYM and MOP treatment (T3) registered higher available phosphorous content with values of 38.30 mg kg^{-1} and 36.45 mg kg^{-1}respectively at 0 and 90 days after incubation.
- Available sulphur content was significantly higher in the treatment containing wood ash, FYM, lime and MOP (T6) with values of 9.01 mg kg^{-1} and 7.77 mg kg^{-1} at 0 and 90 days after incubation.

- The available Ca, Mg, Fe, Mn, Cu and Zn contents in the soil samples showed an increase from 0 to 90 days after incubation in all the treatments except control.
- The treatment containing wood ash, FYM, lime and MOP (T6) showed higher Ca, Mg and Zn contents throughout the period of incubation.
- The value of available calcium content in this treatment (wood ash, FYM, lime and MOP) increased from 493.33 mg kg^{-1} to 716.33 mg kg^{-1} over a period of 0 to 90 days after incubation.
- The available magnesium content in the T6 treatments (wood ash: FYM with lime and MOP)in the soil samples was 130.66 mg kg^{-1} at 0 days and 160.66 mg kg^{-1}at 90 days after incubation.
- The value of available iron content increased from 0 to 90 days except for control and the value was highest for T5 treatment with plantain compost, lime and MOP with values of 14.27 mg $kg^{-1}$and 18.18 mg kg^{-1}respectively at 0 and 90 days after incubation.
- The available manganese content had increased (except for control) from 0 to 90 days and treatment T4 containing rice straw with lime and MOP reported the highest content with values of 36.79 mg $kg^{-1}$and 47.81 mg kg^{-1}respectively at 0 and 90 days after incubation.
- The value of available copper increased from 0 to 90 days except for control and the value was high for plantain compost with lime and MOP (T5) treatment at 0 and 90 days with values of 7.19 mg $kg^{-1}$and 7.87 mg kg^{-1}.
- The value of available zinc content also showed an increment except for control and MOP alone treatment and the value was highest for wood ash: FYM with lime and MOP treatment (T6) with values of 2.79 mg $kg^{-1}$and 3.00 mg kg^{-1}at 0 and 90 days after incubation.

The effect of different organic K resources on different fractions of K are furnished below:

- The total K content in all, the treatments showed a narrowincrease from 0 to 60 days followed by a slight decline after90 days of incubation.

Significantly higher quantity of total K content was registered by treatment containing rice straw with lime and MOP (T4) at all the incubation intervals. The highest valuw was indicated in the treatment containing rice straw with lime and MOP (T4) with a value of 2398.44 mg $kg^{-1.}$

- Over a period of 90 days, exchangeable K content increased uniformly in all treatments without lime. In thelimed treatments, the values increased up to a period of 60 days and then decreased at 90 days whereas control treatment showed a uniform decline in the value throughout the incubation period. After 90 days of incubation, rice straw with lime and MOP (T4) showed significantly higher value.
- The value of non- exchangeable K showed a uniform increase from 0 to 60 days followed by a decrease after 90 days of incubation with the maximum. A higher value was observed in T4 treatment containing rice straw with lime and MOP throughout the incubation period with values of 1003.66 mg kg^{-1}, 1428.33 mg kg^{-1}, 1683.83 mg kg^{-1}, 1726.67 mg kg^{-1} and 1541.50 mg kg^{-1} respectively.
- The value of available K under all treatments (except control) first increased up to 60 days followed by a decrease towards 90 days after incubation
- Significantly higher value of available K was reported under T5 treatment that contained plantain compost with lime and MOP throughout the incubation period with values of 655.83 mg kg^{-1}, 692.50 mg kg^{-1}, 722.91 mg kg^{-1}, 747.92 mg kg^{-1} and 720.00 mg kg^{-1} respectively at 0, 15, 30, 60 and 60 days after incubation.
- The value of water soluble K content has increased under all treatments (except control) from 0 to 60 days followed by a decrease in 90 days after incubation.
- The treatment with wood ash, FYM, lime and MOP (T6) registered significantly higher value throughout the incubation days with values of 296.55 mg kg^{-1}, 330.43 mg kg^{-1}, 345.31 mg kg^{-1}, 346.83 mg kg^{-1} and 317.80 mg kg^{-1} respectively.

The present study revealed that integrated application of organic sources along with lime and MOPwould considerably contributed increment towards different fractions of soil K. The addition of lime along with different organic resources with MOP has contributed to higher levels of different forms of potassium than that of non-limed soils. Comparing the different organic sources application, rice straw with lime and MOP can be considered as the best method towards long term cultivation methods since it contain more K and also retain great amount of total K, non- exchangeable K and exchangeable K in the soil thus enabling the continuous uniform uptake of potassium by the crops for its growth and development. Therefore, combined application of rice straw with lime and MOP can contribute greatly towards different forms of K thereby improving K fertility of soils. At the same time, application of plantain compost with lime and MOP can be considered as a better method for retaining more available K and micro nutrients and are found suitable for lateritic soil by maintaining favourable pH. Preparation of plantain compost is also considered as a promising method for recycling the crop residues obtained after the harvest of banana which is considered to the rich source of potassium. Proper application of wood ash with FYM, lime and MOP can also be considered as an appropriate method for short duration crops since it contains more than 90 % of potassium in water soluble form that can be easily taken up by the plants.

Reference

REFERENCE

Alexander, R., Lingan, B. A. and Poyamolli, G. 2010. Advances in industrial prospective of cellulosic macromolecules enriched banana biofibre resources. *Eur. J. Appl. Sci*. 2: 116-121.

Bandyopadhyay, B.K. and Goswami, N.N., 1985. Potassium activity ratio and potassium uptake in three major soils of India. *Journal of the Indian Society of Soil Science*, *33*(3): 581-585.

Bansal, S.K., Srinivasa, R.C., Pasricha, N.S. and Patricia, I. 2002. Potassium dynamics in major benchmark soil series of India under long-term cropping. In proceedings of the *17th World congress of soil science,, Bangkok (Thailand), 14-21 Aug 2002*.

Barber, R.G., 1979. Potassium fixation in some Kenyan soils. *Journal of Soil Science*, *30*(4): 785-792.

Bartlet, R. J. and J. L. Mclntosh. 1969. pH dependent bonding of potassium by a spodosol. *Soil Sci. Soc. Am. J*. 33(4): 535-539.

Bastin, B. and Venugopal, V.K., 1986. Available nutrient status of some red soils (Alfisols) from different regions in Kerala. Agricultural Research Journal of Kerala. 24 (1): 22-29.

Basumatary, A. and Bordoloi, P.K., 1992. Forms of potassium in some soils of Assam in relation to soil properties. *Journal of the Indian Society of Soil Science*, *40*(3) : 443-446.

Bear, P. E. 1976. Chemistry of soil Oxford and IBH publishing Co. New Delhi. 2 :280p.

Beringer, H. and Nothdurft, F. 1985. Effects of potassium on plant and cellular structures. *Potassium in agriculture*, 351-367.

Bhatt, R. and Sharma, M., 2011. Potassium Scenario—a Case Study in the Kapurthala District of Punjab, India. *Journal of Research*. 48: 24-27p.

Biswas, C. R. 1974. The potassium supplying capacity of several Philippines soils under two moisture regimes. *Potash Review*, *12*(74): 1-15.

Blake, L., Mercik, S., Koerschens, M., Goulding, K.W.T., Stempen, S., Weigel, A., Poulton, P.R. and Powlson, D.S. 1999. Potassium content in soil, uptake in plants and the potassium balance in three European long-term field experiments. *Plant and Soil*. 216 (1-2): 1-14.

Brar, M.S., Subbarao, A. and Sekhon, G.S. 1986. Solution, exchangeable, and nonexchangeable potassium in five soil series from the alluvial soils region of Northern India. *Soil science*, *142*(4): pp.229-234.

Brar, B. S., &Pasricha, N. S. 1998. Long-term studies on integrated use of organic and inorganic fertilizers in maizewheat-cowpea cropping system on alluvial soil of Punjab. In *Proceedings of a National Workshop on Long-term Soil Fertility Management Integrated Plant Nutrient Supply. Indian Institute of Soil Science, Bhopal, India*: 154-168.

Caporn, S. J. M., Ludwig, L. J., and Flowers, T. J. 1982. Potassium deficiency and photosynthesis in tomato. In *Plant nutrition 1982: proceedings of the ninth International Plant Nutrition Colloquium, Warwick University, England, August 22-27, 1982/edited by A. Scaife*. Slough, UK: Commonwealth Agricultural Bureaux, 1982.

Cervantes, C.E. and Hanson, R.G. 1991. A potential method to incorporate quantity/intensity into routine soil test interpretations. *Communications in soil science and plant analysis*, *22*(7-8): 683-700.

Chandran, P., Ray, S.V., Bhattacharyya, T., Srivastava, P., Krishnan, P. and Pal, D.K. 2005. Lateritic soils of Kerala, India: their mineralogy, genesis, and taxonomy. *Soil Research*, *43*(7) : 839-852.

Cheshire, M.V. and Chapman, S.J. 1996. Influence of the N and P status of plant material and of added N and P on the mineralization of C from 14 C-labelled ryegrass in soil. *Biology and Fertility of Soils*. *21*(3) :166-170.

Das, K., Dang, R., Shivananda, T.N. and Sur, P. 2005. Interaction between phosphorus and zinc on the biomass yield and yield attributes of the medicinal plant stevia (Stevia rebaudiana). *TheScientificWorldJournal*. *5* : 390-395.

Demeyer, A., Nkana, J.V. and Verloo, M.G. 2001. Characteristics of wood ash and influence on soil properties and nutrient uptake: an overview. *Bioresource technology*. *77*(3): 287-295.

Deshmukh, V.N. and Khera, M.S., 1990. Potassium supplying power of some Ustochrepts under exhaustive cropping and varying external supply. *PKV Research Journal*, *14*(2) :107-111.

Devi, C. R. S., Karah, P. A., Usha, P. B. and Saraswathy, P. 1990. Forms of potassium in two soil series of south Kerala. *J. Pot. Res*. 6 (1): 9-15.

Dey, P., Santhi, R., Maragatham, S. and Sellamuthu, K.M. 2017. Status of phosphorus and potassium in the Indian soils vis-à-vis world soils. Indian Journal of Fertilisers 13(4), 44-59.

Dhanorkar, B.A., Borkar, D.K., Puranik, R.B. and Joshi, R.P., 1994. Forms of soil potassium as influenced by long-term application of FYM and NPK in Vertisol. *Journal of Potassium Research*, *10*(1):42-48.

Dhillon, S.K., Sidhu, P.S., Dhillon, K.S. and Sharma, Y.P., 1985. Distribution of various potassium forms in some benchmark soils of North-West India. *Journal of potassium research*.

Dobermann A, Fairhurst TH. 2012. Straw management important for developing potassium fertilizer recommendation. Better crop management. 16: 7-10.

Doran, I. B. and S. Z. Kavya. (2005). The effects of compost prepared from waste material of banana on the growth, yield and quality properties of banana plants. J. *Environ. Biol.* 26 (1): 7-12.

Du, Z.Y., Zhou, J.M., Wang, H.Y., Du, C.W. and Chen, X.Q. 2007. Effect of NH4+ on movement and transformation of K+ in fertilizer microsites in soils. *ActaPedologicaSinica*. *44*(3): 492-498.

Eagle, A.J., Bird, J.A., Horwath, W.R., Linquist, B.A., Brouder, S.M., Hill, J.E. and van Kessel, C. 2000. Rice yield and nitrogen utilization efficiency under alternative straw management practices. *Agronomy Journal*, *92*(6): 1096-1103.

Ekambaram, S. and Kothandaraman G.V. 1983. Influence of potassium application on the progressive changes in the different forms of K in soils during crop growth. *Indian Potash J.* 8: 16-20.

Erich, M.S. 1991. Agronomic effectiveness of wood ash as a source of phosphorus and potassium. *American Society of Agronomy*. 20(3): 576-581.

Erich, M.S. and Hoskins, B.R. 2011. Effects of soil drying on soil pH and nutrient extractability. *Communications in soil science and plant analysis*, *42*(10) :1167-1176.

Erich, M.S. and Ohno, T. 1992. Phosphorus availability to corn from wood ash-amended soils. *Water, Air, and Soil Pollution*. *64*(3): 475-485.

Evans, C.E. and Attoe, O.J. 1948. Potassium-supplying power of virgin and cropped soils. *Soil Science*, *66*(5): 323-334.

FAI. 2016. Fertiliser Statistics, 2019-20. 64th Edition. The Fertiliser Association of India, FAI House, New Delhi.

Fanning, D. S., Keramidas, V. Z., and El-Desoky, M. A. 1989. Micas. *Minerals in soil environments*, *1*, 551-634.

Freundlich, H. 1906. Over the adsorption in solution. *J. Phys. Chem***.** 57: 1100–1107.

Ganai, J. Q., Singh, J. P. and Antil R. S. 2013. Long-term effect of continuous cropping and differential nutrient management practices on P and K dynamics under rice-wheat cropping system. Indian J Fertilizers. 9: 26-40.

Ghosh, A. B. and Hassan, R. 1976. Available potassium status of India Soils. *Bulletin of the Indian Society of Soil Science.* 10: 6-12.

Ghosh, A. B., & Hasan, R. (1977). Available potassium status of Indian soils. *Journal of the Indian Society of Soil Science.* 33: 392-396.

Ghosh, B.N. and A. K. Mukhopadhyay, A.K. *Annals of Agricultural Research*. 2001. 22: 377.

Golakiya, B.A., Gundalia, J.D. and Polara, K.B., 2001, December. Potassium dynamics in the soils of Saurashtra. In *Poster at the IPI-PRII International Symposium on the" Importance of potassium in nutrient management for sustainable crop production in India*. 3-5p.

Grover, S.P., Butterly, C.R., Wang, X. and Tang, C. 2017. The short-term effects of liming on organic carbon mineralisation in two acidic soils as affected by different rates and application depths of lime. *Biology and Fertility of Soils*, *53*(4) : 431-443p.

Guan, X.K., Wei, L., Turner, N.C., Ma, S.C., Yang, M.D. and Wang, T.C., 2020. Improved straw management practices promote in situ straw decomposition and nutrient release, and increase crop production. *Journal of Cleaner Production*, *250*:119514p.

Gupta, R.D., Jha, K.K. and Sahi, B.P., 1983. Characterisation of Floating Islands of Kashmir with Reference to Their Mineralogy and Microbiology. *Journal of the Indian Society of Soil Science*, *31*(1), pp.140-142.

Hasan, R., 2002. Potassium status of soils in India. *Better Crops Int*. *16*(2: 3-5p.

Havlin, J. L., Westfall, D. G., and Olsen, S. R. 1985. Mathematical models for potassium release kinetics in calcareous soils. *Soil Science Society of America Journal*, *49*(2), 371-376.

Jackson ML. 1973. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd, New Delhi, pp 498.

Jain, N., Bhatia, A. and Pathak, H. 2014. Emission of air pollutants from crop residue burning in India. *Aerosol and Air Quality Research*, *14*(1) : 422-430.

Jansone, L., Von Wilpert, K. and Hartmann, P. 2020. Natural Recovery and Liming Effects in Acidified Forest Soils in SW-Germany. *Soil Systems*. *4*(3): 38p.

Jin, S., Jin, W., Dong, C., Bai, Y., Jin, D., Hu, Z. and Huang, Y. 2020. Effects of rice straw and rice straw ash on rice growth and α-diversity of bacterial community in rare-earth mining soils. *Scientific reports*. *10* (1) : 1-12.

Johnston, A.E. and Mitchell, J.D. 1974. The behavior of K remaining in soils from the Agdell experiment at Rothamsted, the results of intensive cropping in pot experiments and their relation to soil analysis and the results of field experiments. *Rothamsted Experimental Station Report* for 1973., Part-2, pp. 74–97.

Kadrekar, S.B. and Kibe, M.M., 1973. Release of soil potassium on wetting and drying. *Journal of the Indian Society of Soil Science*, *21*(2), pp.161-166.

Kanwar, R. and Singh, R. 1989. Forms of potassium in some soils of citrus orchard of Chamoli district of Uttar district of Uttar Pradesh hills. Indian Journal of Agricultural Research. 23(1): 39-42.

KAU [Kerala Agricultural University]. 2016. Package of Practices Recommendations: Crops (15th Ed.). Kerala Agricultural University, Thrissur, 393p.

Kaur, N. and Benipal D. S. 2006. Effect of crop residue and farmyard manure on K forms on soils of long-term fertility experiment. Indian J Crop Sci. 1: 161-164.

Kavitha, P., Ravikumar, G. and Manivannan, S. 2011. Vermicomposting of banana agro waste using an epigeic earthworm, *Eudriluseugeniae*. *Global J. Environ. Res*. 5: 53-56.

Ke, X., Zhang, Y., Li, P. J. and Li, R. D. 2009. Study on mechanism of chestnut inner shells removal of heavy metals from acidic solutions. *Journal of Shenzhen University (Science & Engineering)* 26: 72–76.

Kittrick, J.A., 1966. Forces involved in ion fixation by vermiculite. *Soil Science Society of America Journal*. *30*(6): 801-803.

KSPB [Kerala State Planning Board]. 2013. Soil Fertility Assessment and Information Management for Enhancing Crop Productivity in Kerala. Government of Kerala, pp 152-154.

Kumar, R., Aslam, M., Raj, V.P., Radhakrishnan, T., Kumar, K.S. and Manojkumar, T. 2016. A statistical analysis of soil fertility of Thrissur district, Kerala. *International Conference on Data Science and Engineering (ICDSE)*, 1-5.

Ladha, J. K., Dawe, D., Pathak, H., Padre, A.T., Yadav, R. L., Singh, B., Singh, P., Kundu, A. L., Sakal, R., Ram, N., Regmi, A. P., Gami, S. K. , Bhandari, A. L., Amin, R., Yadav, C. R., Bhattarai, E. M., Das, S., Aggarwal, H. P., Gupta, R. K. and Hobbs, P. R. 2003. How extensive are yield declines in long- term rice-wheat experiment in Asia? *Field Crops Res.* 132: 204-212.

Lakkineni, K.C. and Abrol, Y.P. 1994. Sulphur requirement of crop plants: physiological analysis. *Fertiliser News*. 39 (3): 11-18.

Lal, J. K., Mishra, B. and Sarkar, A. K. 2000. Effect of Plant Residues incorporation on specific microbial groups and availability of some plant nutrients in soil. *J. Indian Soc. Soil Sci*. 48: 67-71.

Langmuir, I. 1918. The adsorption of gases on plane surfaces of glass, mica and Platinum. *J. Am. Chem. Soc.*40: 1361–1403.

Lerner, B.R. and Utzinger, J.D. 1986. Wood ash as soil liming material. *HortScience*. *21*(1): 76-78.

Li, J., Lu, J., Li, X., Ren, T., Cong, R. and Zhou, L. 2014. Dynamics of potassium release and adsorption on rice straw residue. *PLoS One*. *9*(2): .e90440.

Liao, Y. L, Zheng, S. X., Nie, J., Xie, J. and Lu, Y. H. 2013. Long-Term Effect of Fertilizer and Rice Straw on Mineral Composition and Potassium Adsorption in a Reddish Paddy Soil. *Journal of Integrative Agriculture*. 12: 694–710.

Louis, J. 1994. *Potassium release and exchange characteristics of the selected wetland rice soils of Kerala*. Kerala Agricultural University. 85p.

Majumdar, K., Sanyal S.K., Singh, V.K., Dutta, S., Satyanarayana, T. and Dwivedi, B.S. 2017. Potassium Fertiliser Management in Indian Agriculture: Current Trends and Future Needs. Indian Journal of ferilisers. 13(5): 20-30.

Majumdar, K., Sanyal, S.K., Dutta,S.K., Satyanarayana, T. and Singh,V.K. 2016. Nutrient mining: addressingthe challenges to soil resources andfood security. *In Biofortification of FoodCrops*, (U. Singh, C.S. Praharaj, S.S.

Martin, H. W. and Sparks, D. L. 1983. Kinetics of nonexchangeable potassium release from two coastal plain soils. *Soil Science Society of America Journal*, *47*(5), 883-887.

Mary, B., Recous, S., Darwis, D. and Robin, D. 1996. Interactions between decomposition of plant residues and nitrogen cycling in soil. *Plant and soil*, *181*(1) :71-82.

Maurya, P.R. and Ghosh, A.B., 1972. Effect of long-term manuring and rotational cropping on fertility status of alluvial calcareous soil. *Journal of the Indian Society of Soil Science*, *20*(1) : 31-43p.

Mawahib. E., N. El-Fadil, A.G. Manal, F.A. Badr and A. E. Saeed. (2015). Effects of banana compost on growth, development and productivity of sorghum bicolor cultivar. J. Adv. Biol. 8 (2): 1555-1565.

Mayadevi, M. R., Sushama, P. K. and Sandeep, S. 2017. Effect of insitu bioconversion of farm residues on growth and quality of banana. *cv. Nendran*in laterite soils of Kerala. *JEBAS*. 5(3): 341-350.

McLean, E. O., 1971. Potentially beneficial effects from liming: chemical and physical. *Soil Crop and Science Society of Florida*. 31: 189-196.

Mehlich, A. 1943. Base saturation and pH in relation to liming and nutrient conservation of soil. *Soil Sci. Soc. Am. J. 7*: 353-361.

Mehta, S.C. and Singh, M., 1986. Potassium adsorption kinetics in some soils samples. *Journal of the Indian Society of Soil Science*, *34*(3), pp.484-487.

Mengel, K., &Kirkby, E. A. 1980. Potassium in crop production. *Advances in agronomy*, *33*, 59-110.

Miller, J. D., Anderson, H. A., Harriman, R. and Collen, P. 1995. The consequences of liming a highly acidified catchment in central Scotland. *Water, Air, and Soil Pollution*, 85, 1015–1020.

Mishra, B.B., Mall, J., Choudhary, J. and Singh, R.A., 2001, Nutrientmining in different agro-climatic zones of Bihar. Fert. News. 46 (11):21-43.

Mittal, S. B., Singh, R., Mehta, S. C. and Singh, M. 1990. Potassium depletion under long-term fertilization in a semi-arid soil in India. *The Journal of Agricultural Science*, *115*(2): 173-178.

Naidu, L.G.K., Ramamurthy, V., G.S. Sidhu and Dipak Sarkar. 2011. Emerging deficiency of potassium in soils and crops of India. Karnataka J. Agric.Sci. 24 (1): 12-19.

Nair, K.H. 1973. Studies on the fertility status of red soils of kerala and the effect of adding nitrogen in combnation with MnO_2 on the growth, yield and composition of rice. M.Sc (Ag) thesis. Kerala Agricultural University.

Nash, V.E. 1971. Potassium release characteristics of some soils of the Mississippi coastal plain as revealed by various extracting agents. *Soil Science*, *111*(5) : 313-317.

NBSS and LUP, National Bureau of Soil Survey and Land Use Planning. 1999. Resource Soil Survey and Mapping of Rubber Growing Soils of Kerala and Tamil Nadu, Nagpur pp.289.

Nguyen, H.X., Nguyen, V.T., Tran, C.T., Nguyen, A.T., Nguyen-Thanh, L., Bui, A.T., Dultz, S., Wu, T.Y. and Nguyen, M.N., 2019. Characterization and implication of phytolith-associated potassium in rice straw and paddy soils. *Archives of Agronomy and Soil Science*, *65*(10), pp.1354-1369.

Nkana, J.V., Demeyer, A. and Verloo, M.G. 1998. Chemical effects of wood ash on plant growth in tropical acid soils. *Bioresource Technology*, *63*(3): 251-260.

Nkana, J.V., Demeyer, A. and Verloo, M.G. 2002. Effect of wood ash application on soil solution chemistry of tropical acid soils: incubation study. *Bioresource Technology*, *85*(3): 323-325.

Ohno, T. and Erich, M.S. 1994. TB154: Phosphorus and Potassium Availability in Wood Ash-Amended Soils: An Incubation Study.

Pal, S.K. and Mukhopadhyay, A.K., 1992. Distribution of different forms of potassium in profiles of some Entisols. *Journal of the Indian Society of Soil Science*, *40*(2):371-373.

Pappu, A., Patil, V., Jain, S., Mahindrakar, A., Haque, R. and Thakur, V.K. 2015. Advances in industrial prospective of cellulosic macromolecules enriched banana biofibre resources: A review. *International journal of biological macromolecules*, *79*: 449-458.

Patel, K. A., Kalyanasundharam, N. G., Patil, R. G. and Pavaya, R. P. 1993. Potassium in Gujarat agriculture- An overview. *Workshop on Potassium in Gujarat Agriculture*. 1-11 p.

Powell Jr, A. J. and Hutcheson Jr, T. B. 1965. Effect of lime and potassium additions on soil potassium reactions and plant response. *Soil Science Society of America Journal*, *29*(1): 76-78.

Prakash, C. and Singh, V., 1985. Forms of potassium in alluvial soils of Western Uttar Pradesh. *Journal of the Indian Society of Soil Science*, *33*(4): 911-914.

Quirk, J. P. and Chute, J. H. 1968. Potassium release from mica-like clay minerals. *IntSoc Soil Sci Trans*.2: 671-681.

Rajasekharan, P., Nair, K.M., Rajasree, G. and Kutty, M.N. 2013. Soil fertility assessment and information management for enhancing crop productivity in Kerala. *Kerala State Planning Board*. 514p.

Ramamoorthy, B. and Bajaj, J. C. 1969. Available N, P and K status of Indian soils. Fertiliser News 14(8), 24-26

Ramamoorthy, B. and Velayutham, M., 1976. Nitrogen, phosphorus and potassium in soil--chemistry, forms and availability. *Soil Fertility: Theory and Practice*. 156-201p.

Ramamoorthy, B., and Bajaj, J. C. 1969. Available nitrogen, phosphorus and potassium status of Indian soils. *Fertilisernews*.14 (8): 24-26.

Ramanathan, K.M. and Krishnamoorthy, K.K. 1978. A study of the relationship between certain soil characteristics and K fixation [India]. *Mysore Journal of Agricultural Sciences*.

Ranganathan, A. and Satyanarayana, T., 1980. Studies on potassium status of soils of Karnataka. *Journal of the Indian Society of Soil Science*, *28*(2): 148-153.

Rani, M., Jha, A.K., Bihari, B., Kumar, A. and Kumar, A. 2020. An Incubation Experiment to Study Potassium Fractions using Azolla, Vermicompost and Muriate of Potash as Potassium Sources in Inceptisol of Bihar. *Journal homepage: http://www. ijcmas. Com*.*9*(5): 2573-2582 p.

Reitemeier, R.F. 1951. Soil potassium. In *Advances in agronomy* (Vol. 3, pp. 113-164). Academic Press.3 : 113-164p.

Rheinheimer, D. S., Tiecher, T., Gonzatto, R., Zafar, M. and Brunetto, G. 2018. Residual effect of surface applied lime on soil acidity properties in a long-term experiment under no-till in a southern sandy soil. *Geoderma*. 313: 7-16.

Rich, C.I. and Black, W.R. 1964. Pottasium exchange as affected by cation size, PH, and mineral structure. *Soil Science*, *97*(6) : 384-390p.

Rich, C.I., 1972. Potassium in soil minerals. **In***Proceedings of the 9th colloquium International Potash Institute.* 9: 15-31p.

Rocha, C. G., Zaia, D. A. M., Alfaya, R. V. S. and Alfaya, A. A. S. 2009. Use of rice straw as biosorbent for removal of Cu(II), Zn(II), Cd(II) and Hg(II) ions in industrial effluents. *J Hazard Mater* 166: 383–388.

Rodriguez-Lizana, A., Carbonell, R., Gonzalez, P. and Ordonez, R. 2010. N, P and K released by the field decomposition of residues of a pea-wheat-sunflower rotation. *Nutrient Cycling in Agroecosystems*. *87*(2): 199-208.

Sadusky, M.C., Sparks, D.L., Noll, M.R. and Hendricks, G.J., 1987. Kinetics and mechanisms of potassium release from sandy Middle Atlantic Coastal Plain soils. *Soil Science Society of America Journal*, *51*(6), pp.1460-1465.

Sain, P. and Broadbent, F.E. 1977. Decomposition of rice straw in soils as affected by some management factors. American Society of Agronomy. 6 (1): 96-100.

Sanyal, S.K., Majumdar, K. and Singh,V.K. 2014. Nutrient management inIndian agriculture with specialreference to nutrient mining – A relook. *Journal of the Indian Society of Soil Science.* 62: 307-325.

Sarkar, G.K., Chattopadhyay, A.P. and Sanyal, S.K. 2013. Release pattern of non-exchangeable potassium reserves in Alfisols, Inceptisols and Entisols of West Bengal, India. *Geoderma*. *207*: pp.8-14.

Scheffer, F., Welte, E. and Reichenbach, H.G.V., 1960. The potassium economy and mineral status of the Gottingen E-plot. *Zeitschrift fur Pflanzenernahrung, Dungung und Bodenkunde*, *88*: 115-128p.

Schroeder, D., 1978. Structure and weathering of potassium containing minerals. In: Potassium research- Review and Trends, proceedings of 11th Congress of the International Potash Institute, Berne. 4: 43-65p.

Sekhon, G. S., & Singh, M. 1982. Potassium status of soils and crop responses to potassium in India. *Fertiliser news*. 27: 15-22.

Sekhon, G.S. and Subba Rao, A., 1985. Potassium availability in soils of Southern India. *Potassium in the agricultural systems of the humid tropics*, pp.207-225.

Sekhon, G. S., Brar, M. S. and Subba Rao, A. 1992. Potassium in some benchmark soils of India.105-111p.

Sekhon, G.S., 1995. Characterization of K availability in paddy soils -Present status and future requirements. *Potassium in Asia–Balanced Fertilization to Increase and Sustain Agricultural Production, IPI, Basel, Switzerland*, pp.115-133.

Sharma, B.D. and Mishra, B. 1986. Potassium reserve and its fractionation in alluvial soils of western Uttar Pradesh. *Journal of potassium research*. 2 (3): 90-95.

Sharma, J. S. and Swarup, A. 2001. Impact of intensive cropping on soil and K sustainability of crop production. In *International Symposium on importance of K in nutrient management for sustainable production in India (Eds. NS Pasricha and SK Bansal). PRII and IPI, New Delhi*, India. 3-5 December.

Sharma, O.P. and Dubey, D.D. 1988. Potassium status of vertisols and associated soils in a toposequence. *Journal of the Indian Society of Soil Science*, *36*(2) : 363-366p.

Sharpley, A. N. 1989. Relationship between soil potassium forms and mineralogy. *Soil Science Society of America Journal*. 536: 1023-1028.Singh and N.P. Singh, Eds.), Springer (India), pp. 177–198. ISBN 978-81-322-2714. DOI 10.1007/978-81-322-2716-8-14.

Singh, B.P., Singh, M. and Shukla, U.C. 1983. Forms of potassium in some soils of different agro-climatic regions of Eastern Haryana. *Journal of the Indian Society of Soil Science*, *31*(1): 31-37.

Singh, H. 1995. Nitrogen mineralization, microbial biomass and crop yield as affected by wheat residue placement and fertilizer in a semiarid tropical soil with minimum tillage. *J. Appl. Ecol*. 32, 588–595.

Singh S. 1979. Potassium supplying capacity of some benchmark soils of Punjab. M.Sc (Ag) thesis, Punjab Agricultural University. 120p.

Singh, M., Singh, A.P. and Mittal, S.B. 1987. Effect of long-term fertilization and cropping on the potassium supplying capacity of soils. *Plant and Soil*, *65*(3): 375-382p.

Singh, O.P. and Datta, B., 1986. Forms of potassium in some soils of Mizoram. *Journal of the Indian Society of Soil Science*, *34*(1), pp.187-190.

Singh, S. 2016. Short communication status of potassium in pearl millet soils of agra, uttarpradesh. *Annals of Plant and Soil Research*, *18*(3), pp.296-297.

Singh, Y. and Singh, B. 2001. Efficient management of primary nutrients in the rice-wheat system. *Journal of Crop Production*, *4*(1): 23-85.

Singh, Y.P., Srngh, M. and Kumar, R., 1985. Identification of potash bearing minerals in the sand fraction of some soils of Haryana. *Journal of the Indian Society of Soil Science*, *33*(3):732-734p.

SOPIB. Sulphate of Potash Information Board.2001. Website at www.sopib.com.

Sparks, D.L., 1980. Chemistry of soil potassium in Atlantic Coastal Plain soils: A review. *Communications in Soil Science and Plant Analysis*, *11*(5): 435-449p.

Sparks, D. L. and Huang, P. M. 1985. Physical chemistry of soil potassium. *Potassium in agriculture*, 201-276.

Sparks, D.L. and Huang, P.M., 1985. Physical chemistry of soil potassium. *Potassium in agriculture*. 201-276p.

Sparks, D. L. (1987). Potassium dynamics in soils. In *Advances in soil science. 6:* 1-63.

Sparks, D.L., 1987. Potassium dynamics in soils. In *Advances in soil science*.6: 1-63p.

Srinivasa Rao, C.H. and Khera, M.S. 1994. Potassium replenishment capacity of illitic soils at their minimal exchangeable K in relation to clay mineralogy. *ZeitschriftfürPflanzenernährung und Bodenkunde*, *157*(6): 467-470 p.

SrinivasaraoCh, Vittal KPR, Kundu S, Gajbhiye PN, Vinasankar BM. 2010. Continuouscropping fertilization and organic manure application effects on potassium in Alfisols under arid conditions. Commun Soil Sci Plant Anal. 41: 783-796.

Srinivasarao, C., and Satyanarayana, T. 2012. Potassium mining in Indian agriculture. *Indian Journal of Fertilisers*, *8*(2): 22-29.

Srinivasarao, C., Kundu, S., Ramachandrappa, B. K., Reddy, S., Lal, R., Venkateswarlu, B., Sahrawat, K. L. and Naik, R. P. 2014. Potassium release characteristics, potassium balance, and fingermillet (*Eleusinecoracana*G.) yield sustainability in a 27-year long experiment on an Alfisol in the semi-arid tropical India. *Plant and soil.374*(1-2): 315-330.

Subba Rao, A. and Sekhon, G. S. 1990. Variation in the potassium status of soil developed on different parent materials. *Journal of the Indian Society of Soil Science*. 39: 266-270.

Subba Rao, A., Adinarayana, V. and Rao, I.V., 1984. Quantity-intensity relationships of potassium in representative soils of Andhra Pradesh. *Journal of the Indian Society of Soil Science*, *32*(2) : 240-243.

Sui, N., Zhou, Z. G., Yu, C. R., Liu, R. X., Yang, C. Q. and Zhang, F. 2015. Yield and potassium use efficiency of cotton with wheat straw incorporation and potassium fertilization on soils with various conditions in the wheat– cotton rotation system. Field Crops Research. 2015; 172: 132–144.

Sun, L., Sun, Z., Hu, J., Yaa, O.K. and Wu, J. 2021. Decomposition Characteristics, Nutrient Release, and Structural Changes of Maize Straw in Dryland Farming under Combined Application of Animal Manure. *Sustainability*. *13*(14) : p.7609.

Surekha, K., Reddy, M.N., Rao, K.V. and Cruz, P.C. 2004. Evaluation of crop residue management practices for improving yields, nutrient balance and soil health under intensive rice-rice system. *Journal of the Indian Society of Soil Science*, *52*(4):448-453.

Suthar, S. 2009. Growth and fecundity of earthworms: *Perionyx excavates* and *perionyxsansibaricus* in cattle waste solids. The environmentalists. 29: 78-84.

Tabatabai, M.A. and Chae, Y.M. 1991. .*American Society of Agronomy*. Mineralization of sulphur in soil amended with organic wastes. 20(3): 684-690.

Takahashi, S., Uenosono, S. and Ono, S. 2003. Short-and long-term effects of rice straw application on nitrogen uptake by crops and nitrogen mineralization under flooded and upland conditions. *Plant and soil*. 251(2):291-301.

Tandon, H. L. S. and Sekhon, G. S. 1988. *Potassium research and agricultural production in India*. Fertiliser Development and Consultation Organisation.

Tarafdar, P.K. and Mukhopadhyay, A.K., 1989. Availability of K to crops at minimal exchangeable K level in soil by exhaustive cropping. *Trop. Agric. (Trinidad)*. *66*: 87-90.

Veerkamp, M. T., & Kuiper, P. J. 1982. The uptake of potassium by Carex species from swamp habitats varying from oligotrophic to eutrophic. *PhysiologiaPlantarum*, *55*(3): 237-241.

Venkatesh, M.S. and Satyanarayana, T. 1994. Status and distribution of potassium in Vertisols of north Karnataka. *Journal of the Indian society of soil science*. 42: 229-233.

Wu, J., Guo, X., Wang, Y., Xu, Z. and Lu, J. 2011. Decomposition Characteristics of Rapeseed and Wheat Straws under Different Rice Cultivations and Straw Mulching Models. *Sci. Agric. Sin. 44*: 3351–3360.

Yadav, R. L., Dwivedi, B. S. and Shukla A. 2001. Nutrient mining and apparent balances in different agro-climate zones of Uttar Pradesh. *Fertilizer News* 46: 13-18p.

Yadav, S.K., Benbi, D.K. and Toor, A.S. 2019. Effect of long-term application of rice straw, farmyard manure and inorganic fertilizer on potassium dynamics in soil. *Archives of Agronomy and Soil Science*, *65*(3):374-384.

Yadav, R.S. 2019. Stubble burning: A problem for the environment, agriculture and humans. *Down To Earth. Accessed June*, *4*, 2019.

Yaduvanshi, N.P.S. and Swarup, A. 2006. Effect of long-term fertilization and manuring on potassium balance and non-exchangeable K release in a reclaimed sodic soil. *Journal of the Indian Society of Soil Science*, *54*(2): .203-207.

Zhou, G., Cao, W., Bai, J., Xu, C., Zeng, N., Gao, S. and Rees, R.M. 2019. Non-additive responses of soil C and N to rice straw and hairy vetch (Viciavillosa Roth L.) mixtures in a paddy soil. *Plant and Soil*, *436*(1): 229-244pp.

Zhu, J. X., Yang, W. Q. and He, X. H. 2013 .Temporal dynamics of abiotic and biotic factors on leaf litter of three plant species in relation to decomposition rate along a subalpine elevation gradient. PLoS ONE 8(4): e62073.

UTILISATION OF POTASSIUM RICH CROP RESIDUES FOR RETENTION OF POTASSIUM IN LATERITIC SOIL

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ABSTRACT OF THE THESIS

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Abstract

Potassium is a versatile vital nutrient for regular plant and animal growth and development. It is regarded as a "quality nutrient" because of its multifunctional role in metabolism. Kaolinite clay minerals prevalent in lateritic soils of Kerala, have lower activity and prevent the retention of available forms of potassium. Potassic fertilisers are often overlooked in fertiliser schedules due to their high unsubsidized cost. There are some K rich organic sources that are ignored by the farmers and are left or burnt in the soil. The utilisation of organic K resources like rice straw and plantain compost made from banana wastes are regarded good alternatives for synthetic potassic fertilisers. The present investigation consisted of three experiments viz., (i) assessment of decomposition dynamics of rice straw and its K release, (ii) K adsorption study on rice straw and prepared plantain compost and (iii) an incubation study in lateritic soil with different sources of potassium.

The decomposition rate of rice straw has increased with the period of its incubation and it showed only a partial decomposition of 51.9 % at 90 days due to the presence of more amount of lignin, cellulose and hemicellulose content which takes more time for its degradation. The potassium release rate increased to 84.28 % at 90 days of its decomposition.

The adsorption study on rice straw with different levels of KCl solution at different periods of decomposition revealed that as the solution concentration increased, the quantity of K adsorbed on rice straw also increased along with the increase in incubation period. Similarly, plantain compost that was prepared using vermi technology also showed an increased trend in the value of quantity of K adsorbed on compost as the KCl concentration increased. Because of its smaller particle size and larger surface area, plantain compost has stronger adsorption and buffer power than rice straw.

Rice straw with potash (T1), plantain compost with potash (T2), wood ash, FYM with potash (T3), rice straw with lime and potash (T4), plantain compost with lime and potash (T5), wood ash, FYM with lime and potash (T6), lime and potash (T7), potash alone (T8), and absolute control (T9) treatments were used in the incubation study. The physico-chemical characteristics of soil such as pH, EC, organic carbon, available N, P, Ca, Mg, S, Fe, Cu, Zn, and Mn were determined at initial and final days of incubation.

Data on the different fractions of soil K indicated that the treatment containing rice straw with lime and Muriate of potash (T4) showed the higher value of total K, exchangeable K and non-exchangeable K after 90 days of incubation. The reason might be that the presence of more inter planar sites in rice straw has trapped the K^+ ions in fixed form since the material is not completely decomposed. At the same time incorporation of rice straw has enhanced the CEC of the soil thus enhancing greater adsorption of exchangeable K from unavailable forms by mass effect.

The current study showed that combining organic K resources with lime and K fertilisers resulted in significant increases in soil K fractions. Integrated application of rice straw with lime and K fertiliser can be considered as the best method for long-term cultivation because it has the ability to retain and release more K, particularly non-exchangeable, exchangeable, and total K, allowing for continuous uptake of K by the crops for normal growth and development. The usage of plantain compost in combination with lime and Muriate of potash has resulted in increased availability of K as well as micronutrients by maintaining favourable pH.

സംഗ്രഹം

സസ്യങ്ങളുടെയും മൃഗങ്ങളുടെയും ക്രമമായ വളർച്ചയ്ക്കും വികാസത്തിനും പൊട്ടാസ്യം ഒരു വൈവിധ്യമാർന്ന സുപ്രധാന പോഷകമാണ്. കേരളത്തിലെ ലാറ്ററിറ്റിക് മണ്ണിൽ ധാരാളമായി കാണപ്പെടുന്ന കയോലിനൈറ്റ് കളിമൺ ധാതുക്കൾക്ക് പ്രവർത്തനക്ഷമത കുറവാണ്, കൂടാതെ ലഭ്യമായ പൊട്ടാസ്യത്തിന്റെ രൂപങ്ങൾ നിലനിർത്തുന്നത് തടയുന്നു. ഉയർന്ന സബ്സിഡിയില്ലാത്ത വില കാരണം പൊട്ടാഷ് വളങ്ങൾ വളങ്ങളുടെ ഷെഡ്യൂളിൽ പലപ്പോഴും അവഗണിക്കപ്പെടുന്നു. K സമ്പന്നമായ ചില ജൈവ സ്രോതസ്സുകളുണ്ട്, അത് കർഷകർ അവഗണിക്കുകയും മണ്ണിൽ ഉപേക്ഷിക്കുകയോ കത്തിക്കുകയോ ചെയ്യുന്നു. ജൈവ K വിഭവങ്ങളായ നെല്ല് വൈക്കോൽ, വാഴയുടെ അവശിഷ്ടങ്ങളിൽ നിന്നുള്ള വാഴ കമ്പോസ്റ്റ് എന്നിവയുടെ ഉപയോഗം സിന്തറ്റിക് പൊട്ടാഷ് വളങ്ങൾക്ക് നല്ല ബദലായി കണക്കാക്കപ്പെടുന്നു. (i) നെല്ല് വൈക്കോലിന്റെ വിഘടിപ്പിക്കൽ ചലനാത്മകതയും അതിന്റെ K പ്രകാശനവും വിലയിരുത്തൽ, (ii) നെല്ല് വൈക്കോൽ, തയ്യാറാക്കിയ വാഴ കമ്പോസ്റ്റ് എന്നിവയെക്കുറിച്ചുള്ള K അഡ്സോർപ്ഷൻ പഠനം, (iii) ലാറ്ററിറ്റിക് മണ്ണിൽ ജൈവ K വിഭവങ്ങൾ ഉപയോഗിച്ചു കൊണ്ടുള്ള ഇൻകുബേഷൻ പഠനം എന്നിങ്ങനെ മൂന്ന് പരീക്ഷണങ്ങളാണ് ഇപ്പോഴത്തെ അന്വേഷണത്തിൽ ഉൾപ്പെട്ടിരിക്കുന്നത്.

നെല്ല് വൈക്കോലിന്റെ ഇൻകുബേഷൻ കാലഘട്ടത്തിൽ അതിന്റെ ദ്രവീകരണ നിരക്ക് വർദ്ധിച്ചു, കൂടാതെ ലിഗ്നിൻ, സെല്ലുലോസ്, ഹെമിസെല്ലുലോസ് എന്നിവയുടെ കൂടുതൽ അളവിലുള്ള ഉള്ളടക്കം കാരണം 90 ദിവസത്തിനുള്ളിൽ 51.9% ഭാഗികമായ വിഘടനം മാത്രമേ കാണിക്കൂ. പൊട്ടാസ്യം വിഘടിപ്പിച്ച് 90 ദിവസത്തിനുള്ളിൽ 84.28% ആയി വർദ്ധിച്ചു.

വിഘടിക്കുന്നതിന്റെ വിവിധ കാലഘട്ടങ്ങളിൽ KCl ലായനിയുടെ വിവിധ തലങ്ങളിലുള്ള നെല്ല് വൈക്കോലിനെക്കുറിച്ചുള്ള അഡ്സോർപ്ഷൻ പഠനം വെളിപ്പെടുത്തി, ലായനി സാന്ദ്രത വർദ്ധിക്കുന്നതിനനുസരിച്ച്, ഇൻകുബേഷൻ കാലയളവിലെ വർദ്ധനവിനൊപ്പം അരി വൈക്കോലിൽ ആഗിരണം ചെയ്യപ്പെടുന്ന കെയുടെ അളവും വർദ്ധിച്ചു. അതുപോലെ, വെർമി സാങ്കേതികവിദ്യ ഉപയോഗിച്ച് തയ്യാറാക്കിയ വാഴ കമ്പോസ്റ്റും കെസിഎൽ സാന്ദ്രത വർദ്ധിക്കുന്നതിനനുസരിച്ച് കമ്പോസ്റ്റിൽ ആഗിരണം ചെയ്യപ്പെടുന്ന

കെയുടെ അളവിൽ വർധിച്ച പ്രവണത കാണിച്ചു. ചെറിയ കണിക വലിപ്പവും വലിയ ഉപരിതലവും കാരണം, വാഴ കമ്പോസ്റ്റിന് അരി വൈക്കോലിനേക്കാൾ ശക്തമായ ആഗിരണവും ബഫർ ശക്തിയും ഉണ്ട്.

കുമ്മായം മ്യൂറിയേറ്റ് ഓഫ് പൊട്ടാഷ് എന്നിവയോടൊപ്പം അരി വൈക്കോൽ അടങ്ങിയ ചികിത്സ, (T4) 90 ദിവസത്തെ ഇൻകുബേഷനുശേഷം, കൈമാറ്റം ചെയ്യാവുന്ന K, കൈമാറ്റം ചെയ്യാനാകാത്ത K, എന്നിവയുടെ ഉയർന്ന മൂല്യം കാണിക്കുന്നതായി മണ്ണിന്റെ വിവിധ ഭിന്നസംഖ്യകളെക്കുറിച്ചുള്ള ഡാറ്റ സൂചിപ്പിച്ചു. കാരണം, വസ്തു പൂർണമായി വിഘടിപ്പിക്കപ്പെടാത്തതിനാൽ നെല്ല് വൈക്കോലിൽ കൂടുതൽ ഇന്റർ പ്ലാനർ സൈറ്റുകളുടെ സാന്നിധ്യം K + അയോണുകളെ സ്ഥിരമായ രൂപത്തിൽ കുടുക്കി. അതേ സമയം അരി വൈക്കോൽ സംയോജിപ്പിക്കുന്നത് മണ്ണിന്റെ CEC വർദ്ധിച്ചിരിക്കുന്നു, അങ്ങനെ മാസ് ഇഫക്റ്റ് വഴി ലഭ്യമല്ലാത്ത രൂപങ്ങളിൽ നിന്ന് കൈമാറ്റം ചെയ്യാവുന്ന കെയുടെ കൂടുതൽ ആഗിരണം വർദ്ധിപ്പിക്കുന്നു.

ജൈവ കെ വിഭവങ്ങൾ കുമ്മായം, കെ വളങ്ങൾ എന്നിവയുമായി സംയോജിപ്പിക്കുന്നത് മണ്ണിന്റെ കെ ഭിന്നസംഖ്യകളിൽ ഗണ്യമായ വർദ്ധനവിന് കാരണമാകുമെന്ന് നിലവിലെ പഠനം തെളിയിച്ചു. കുമ്മായം, കെ വളം എന്നിവ ഉപയോഗിച്ച് നെല്ല് വൈക്കോൽ സംയോജിതമായി പ്രയോഗിക്കുന്നത് ദീർഘകാല കൃഷിക്കുള്ള ഏറ്റവും നല്ല മാർഗ്ഗമായി കണക്കാക്കാം, കാരണം ഇതിന് കൂടുതൽ കെ, പ്രത്യേകിച്ച് കൈമാറ്റം ചെയ്യാനാകാത്തതും കൈമാറ്റം ചെയ്യാവുന്നതും മൊത്തം കെയും നിലനിർത്താനും പുറത്തുവിടാനും കഴിയും, ഇത് തുടർച്ചയായി ആഗിരണം ചെയ്യാൻ അനുവദിക്കുന്നു. സാധാരണ വളർച്ചയ്ക്കും വികാസത്തിനും വിളകൾ വഴി കെ. കുമ്മായം, മ്യൂറിയേറ്റ് ഓഫ് പൊട്ടാഷ് എന്നിവയ്ക്കൊപ്പം വാഴ കമ്പോസ്റ്റിന്റെ ഉപയോഗം അനുകൂലമായ പിഎച്ച് നിലനിർത്തുന്നതിലൂടെ കെയുടെയും മൈക്രോ ന്യൂട്രിയന്റുകളുടെയും ലഭ്യത വർദ്ധിപ്പിക്കുന്നതിന് കാരണമായി.