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Different Forms of Potassium and Their Contributions toward Potassium Uptake under Ginger (Zingiber officinale Roscoe) Production in an Ultisol of Umudike, Southeastern Nigeria

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ABSTRACT

Field experiments were carried out in 2018 and 2019 at the National Root Crops Research Institute Eastern Farm, Umudike, Southeastern Nigeria to examine the different forms of potassium and their contributions toward potassium uptake under ginger production using ginger variety (UG 1) as the test crop. There were seven treatments consisting of sole and combinations of NPK15:15:15, poultry manure and rice mill waste with a rate of 45kg N/ha regarded as 100%. They were arranged in RCBD with three replications. The available potassium in 2018 and 2019 were 0.080 and 0.100 cmol/kg. They were low in status. The variations in different forms of K status were due to the application of mineral and organic fertilizers. Among the five forms, water-soluble K and total K contributed predominantly to K uptake by ginger. The highest yield of 49.6 and 47.5 t/ha and K uptake of 128.5 and 127.5 kg/ha were obtained from 50% NPK and 50% rice mill waste at 5 MAP; and the highest yield of 49.6 and 51.0 t/ha and K uptake of 160.8 and 158.7 kg/ha were obtained from 50% NPK and 50% poultry manure at 8 MAP in 2018 and 2019, respectively. It can therefore be concluded that combination of NPK fertilizer with rice mill waste will give a better yield and K uptake of ginger if harvested earlier at 5 MAP while poultry manure with NPK15:15:15 is a promising amendment for increasing soil forms of K, K uptake and yield of ginger at 8 MAP in Umudike.

1.0. Introduction

Potassium is more abundant than phosphorus in plant cells and the second most abundant nutrient after nitrogen in plant leaves (Sardans *et al*., 2012). The terrestrial ecosystems such as forests and shrub lands have a great biological capacity for retention of potassium by several processes, such as plant 'pumping' and resorption of K (Nowak *et al*., 1991). Many tropical and subtropical soils are poor in mobile compounds of phosphorus, nitrogen and to a lesser extent potassium. The potassium content in tropical soils differ depending on the extent of weathering of their mineral part; the greater the level of weathering, the lower the content of potassium in the soil (Harsha and Jagadeesh, 2017). Availability of soil K to plant is controlled by dynamic interactions among its different chemical forms (Wang *et al.,* 2004). The components of dynamic interactions are: water soluble K, which is taken up directly by plants; exchangeable K, held by negatively charged sites of clay particles; nonexchangeable K, which is trapped between layers of expanding lattice clays; and lattice K, an integral part of the primary minerals (Srinivasarao *et al*., 1997). The removal of plant nutrients, especially K, is greater under imbalanced fertilizer application in an intensive cropping system (Lal *et al*., 2002). Accumulation of K in plant parts is dependent upon its availability in soil. Any depletion in K form is likely to shift the equilibrium in the direction to replenish it (Sanyal and Majumdar, 2001).

Ginger has a high nutrient demand. Organic manure such as green manure, compost, wood ash or farmyard manure should be applied to improve the water and nutrient holding capacity of the soil (Dauda *et al.,* 2008).The objective of this study was to investigate the effects of sole and combined treatments of NPK 15:15:15, poultry manure and rice mill waste on soil forms of K, K uptake and yield of ginger in Umudike, Southeastern Nigeria.

2.0. Materials and Methods

2.1. Study Area

The field experiment was conducted in 2018 and 2019 at the National Root Crops Research Institute, Eastern Farm, Umudike Abia State. Umudike is located on latitude -$05^0 27'$ North and longitude -$07^0 32'$ East with an altitude of 123 meters above sea level. Umudike is located within the tropical rainforest zone with a mean rainfall range of 1512 – 2200 mm, distributed over nine to ten months in a bimodal rainfall pattern. These are the early rain (April-July) and late rain (August-October) with five months of the dry season and a short dry spell in August. The monthly minimum air temperature ranged from 20^0C to 24^0C, while the monthly maximum air temperature ranged from 28^0C to 35^0C (NRCRI, Umudike Meteorological Station, 2014). Both soils were classified as Typic Paleudults by USDA classification (Chukwu, 2013).

2.2. Soil Sampling, Planting Material and Amendments

Soil samples were collected randomly at 0-20 cm depth from the two years trial before the commencement of the experiment, bulked, and a composite sample was taken for analysis. At the end of the experiment, three auger samples were taken per plot at the same depth, bulked, and a composite sample was taken for analysis. The composite soil samples were air-dried and passed through a 2 mm sieve for laboratory analysis. Ginger (*Zingiber officinale* Rosc) UG 1 variety was obtained from National Root Crops Research Institute, Maro sub-station, Kaduna State. The poultry manure was collected from a commercial poultry farm in Umudike. Rice mill waste was obtained from the Bende Local Government Area of Abia State, while the NPK fertilizer was purchased from an open market in Umuahia town.

2.3. Experimental Layout and treatments

The treatments were laid out in a Randomized Complete Block Design (RCBD) with three replications. The study area was mapped out into 21 experimental plots. Each plot measured 1 m × 2 m with inter plot distance of 0.5 m and inter replicate distance of 2 m. The experimental plots were manually tilled into beds. In both 2018 and 2019 studies, the treatments were:

Control (no treatment)

100% NPK15:15:15 (45 kg N/ha)

100% Poultry manure (PM) (45 kg N/ha)

100% Rice mill waste (RMW) (45 kg N/ha)

50% NPK (22.5 kg N/ha) + 50% PM (22.5 kg N/ha)

50%NPK (22.5 kg N/ha) + 50% RMW (22.5 kg N/ha)

50% NPK (22.5 kg N/ha) + 25% PM (11.25 kg N/ha) + 25% RMW (11.25 kg N/ha)

2.4. Total N Content in the Organic Amendments used in the Experiment

The organic amendments were applied to specified plots based on their N concentration (Table 2). The N concentration of each amendment was calculated to the quantity of 45 kg N/ha as 100% using the following equation:

100 kg of amendment in kg -------------- N concentration

ϰ amendment (kg N/ha) ------------ 45 kg N/ha

$$\varkappa \text{ amendment (kg N/ha)} = \frac{100 \text{ kg of amendment} \times 45 \text{ kg N/ha}}{\text{N Concentration (kg)}}$$

In 2018, 45 kg N/ha Poultry manure (PM) = 2.1 t/ha and 45 kg N/ha Rice mill waste (RMW) = 3.8 t/ha

In 2019, 45 kg N/ha Poultry manure (PM) = 1.6 t/ha and 45 kg N/ha Rice mill waste (RMW) = 3.4 t/ha

2.5. Planting and data collection

The poultry manure and rice meal waste were incorporated into specified plots one week before planting, as stated by Iren *et al.,* 2011. One seed of ginger was planted per stand at a spacing of 0.2 m by 0.2 m (0.04 m^2), giving a plant population of 250 000 plants ha^{-1}. The NPK fertilizer was applied to specified plots in two doses (split application) 6 and 12 weeks after planting. Mulching was done between 24 to 48 hours after planting with dry leaves of guinea grass (*Panicum maximum*) at 50 t/ha. The farm was kept weed-free throughout the experiment. The ginger plant was planted in May for the 2018 and 2019 planting seasons, and it lasted for eight months in the field. The weights of the fresh rhizomes were taken at harvest, and the K uptake of the ginger rhizome was determined after that.

2.6. Laboratory Analyses

The particle size distribution was done using the Bouyoucos hydrometer method (Sheldrick and Wang, 1993). Soil pH was determined using a ratio of 1: 2.5 in soil water medium and read with a Digital pH - meter (Ibitoye, 2006). Organic carbon content was determined by Walkley and Black (1934) wet dichromate oxidation method. Soil total nitrogen was determined by the micro - Kjeldahl method (Bremner, 1996). The available phosphorus was extracted by the Bray - 2 extractants (Bray and Kurtz, 1945). The available K was extracted with IN NH_4OAc, using a soil: solution volume ratio of 1:10 (IITA, 1989). Water-soluble potassium was determined in 1:10 soil-water suspension (Black, 1965). Non exchangeable K was determined by the boiling of 1N HNO_3 method as outlined by Knudsen *et al*. (1982). The total K was determined by wet acid double extraction using nitric acid (HNO_3) + perchloric acid ($HClO_4$). All the K in the extracts were read using a flame photometer. The quantity of K obtained in water soluble K was subtracted from the NH_4OAc extracted K, to get the exchangeable K content in the soil. The lattice K was computed as difference between total K and the sum of water soluble, exchangeable and non-exchangeable K fractions.

2.7. Ginger Rhizome and Organic Manure Analysis

The fresh samples of the ginger rhizome at harvest, at different treatment levels, were oven-dried at 70 ^{0}C for 72 hours and milled. 0.2g each of the powdered ginger at different treatment levels, and the poultry manure and rice mill waste used for the experiment were extracted using sulphuric acid and perchloric acid. The K in the extract was determined using the standard method listed above.

2.8. Nutrient Uptake

Potassium uptake in ginger rhizome per plot was analyzed using the equation:

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{K Concentration (\%)} \times \text{Dry weight (kg/ha)}}{100}$$

Source: (Rani and Sukumari, 2013)

2.9. Statistical analysis

Analysis of variance was carried out on each of the observation using GENSTAT Statistical package for a randomized complete block design (RCBD) and mean separation was carried out by the Fishers Least Significant Difference (FLSD) at 5% level of probability as outlined by (Obi, 2002).

3.0. Results and Discussion

3.1. Physical and Chemical Properties of the Soil before the Experiment

The physical and chemical properties of the surface soil (0 -20 cm) obtained from the experimental sites are presented in Table 1. The soils of the experimental sites were texturally classified as loamy sand. The soils were strongly acidic with a pH of 4.80 and 4.70 (Chude *et al*., 2005) against the normal range of 5.5 - 6.5 given by Enwezor *et al.* (1990) for soils of Southeastern Nigeria. The soils were low in organic carbon content with the value of 9.20 g/kg and 11.00 g/kg, lower than the critical level of 20.00 g/kg given by Adeuayi *et al*. (2002) for soils of humid tropical region. The total nitrogen content in the soil were also low with 1.12 g/kg and 0.98 g/kg respectively, lower than the critical value of 1.5 g/kg. The finding is in agreement with those reported by Ezeaku (2011). The available phosphorus for 2018 was 18.50 mg/kg which was rated medium while that of 2019 was 24.00 mg/kg and was rated high based on the ratings of Chude *et al.* (2004) and Landon (1991). This indicates that the soil of 2019 may have higher sorption capacity of P than the soil of 2018 due to some climatic factors. At low P range, plants respond to P fertilizer application but not likely at higher levels, so the soils of 2018 will respond more to the fertilizer applications (Orji and Abam, 2018). The available K were 0.080 cmol/kg and 0.100 cmol/kg for 2018 and 2019 respectively. These soils were rated low in K content by the ratings of Udo (1989) who states that values less than 0.200 cmol/kg are considered low, 0.200 to 0.400 cmol/kg medium and values above 0.400 cmol/kg high. The high rainfall in the southeastern Nigeria leads to high rate of leaching of the available K, which could cause soil acidity (Eshiett, 1992). The low available K explains why the soil showed strong acidity (pH 4.80 and 4.70) (Chude *et al*., 2005). This reveals that the soils are highly degraded, which could be due to the climate and parent material of the studied areas (Akamigbo, 1999). The sites were potentially low in fertility and would therefore depend on soil amendments for sustainable agricultural yield.

Table 1: Physical and Chemical Properties of Soil before Experimentation

Soil Properties	**Value**	
	2018	2019
Sand (g/kg)	814.00	850.00
Silt (g/kg)	106.00	46.00
Clay (g/kg)	80.00	104.00
Textural class	Loamy sand	Loamy sand
pH (H_2O)	4.80	4.70
Organic matter (g/kg)	15.90	19.00
Organic carbon (g/kg)	9.20	11.00
Total nitrogen (g/kg)	1.12	0.98
C : N ratio	8.21	11.22
Available phosphorus (mg/kg)	18.50	24.00
Forms of K (cmol/kg)		
Available K	0.080	0.100
Water soluble K	0.018	0.026
Exchangeable K	0.062	0.074
Non exchangeable K	0.105	0.078
Lattice K	0.331	0.336
Total K	0.516	0.513

3.2. Properties of the Manures used for the Experiment

The chemical compositions of poultry manure and rice mill waste are presented in Table 2. From the analysis of the organic manures used for the studies, poultry manure had higher level of total nitrogen (21.0 g/kg and 28.7 g/kg) potassium (29.0 g/kg and 16.6 g/kg) than rice mill waste used for 2018 and 2019 planting seasons. Phosphorus was higher in poultry manure (45.5 g/kg) in 2018 and higher in rice mill waste (35.3 g/kg) in 2019 planting seasons. A lower C: N ratio of 9.5 and 8.9 were obtained from poultry manure in 2018 and 2019 respectively, this showed faster rate of mineralization when compared with C: N ratios of 32.9 and 23.3 obtained from rice mill waste (Iren *et al.,* 2014). The poultry manure and rice mill waste had high levels of nutrient reserve that would be released during mineralization.

3.3. Ginger Rhizome Fresh Yield and Potassium Uptake

The ginger rhizome fresh yield and K uptake during the 2018 and 2019 planting seasons at 5 and 8 months after planting (MAP) are given in Table 3. Application of NPK 15:15:15, poultry manure and rice mill waste in a sole or in a combined form significantly ($p<0.05$) increased the fresh rhizome yield and K uptake of ginger for 2018 and 2019 planting seasons respectively when compared with the control (Table 3).

The yield in 2018 at 5 MAP was highest in plots treated with 50% NPK + 50% rice mill waste (49.6 t/ha), which increased the yield by 103% over the control. The effect of this treat-

Table 2: Nutrient Composition of Organic Manures used for the two Planting Seasons

Parameter	**2018**		**2019**	
	Poultry manure (PM)	**Rice mill waste (RMW)**	**Poultry manure (PM)**	**Rice mill waste (RMW)**
Organic matter (g/kg)	344.5	674.9	449.9	533.9
Organic carbon (g/kg)	199.8	391.5	256.3	309.7
Total Nitrogen (g/kg)	21.0	11.9	28.7	13.3
C:N ratio	9.5	32.9	8.9	23.3
Phosphorus (g/kg)	45.5	32.0	25.8	35.3
Potassium (g/kg)	29.0	19.7	16.6	10.7

ment was significantly ($p<0.05$) higher than other treatments. At 8 MAP, the yield was highest in plots treated with 50% NPK + 50% poultry manure (49.6 t/ha) which increased the yield by 85.2% over the control and was closely followed by 100% poultry manure (47.5 t/ha). The trend of the yield increment was as follows: at 5 MAP; NPK + RMW > NPK + PM + RMW > RMW > NPK + PM > NPK > C, at 8MAP; NPK + PM > PM > NPK + PM + RMW > NPK + RMW > RMW > NPK > C.

In 2019 at 5 MAP, the highest rhizome fresh yield of 47.5 t/ha was still recorded in plots treated with 50% NPK + 50% rice mill waste, which increased the yield by 84.9% over the control. It was significantly ($p<0.05$) higher than other treatments. At 8 MAP, the plot treated with 50% NPK + 50% poultry manure still gave the highest yield of 51.0 t/ha which increased the yield by 80.0% over the control and was closely followed by the plot treated with 100% poultry manure (50.0 t/ha) and it was significantly different ($p<0.05$) from other plots. The trend of the yield increment was as follows: at 5 MAP; NPK + RMW > NPK + PM + RMW > RMW > NPK > NPK + PM > PM > C, at 8 MAP; NPK + PM > PM > NPK + PM + RMW > NPK + RMW > RMW > NPK > C.

K uptake in 2018 at 5 MAP was highest in plots treated with 50% NPK + 50% rice mill waste (128.5 kg/ha), which showed a significant ($p<0.05$) difference with all the sole treated plots and the control having the least value. At 8 MAP, plots treated with 50% NPK + 50% poultry manure was highest in K uptake (160.7 kg/ha) and it did not show any significant ($p<0.05$) difference with plots treated with 100% poultry manure (150.2 kg/ha) and 50% NPK + 25% poultry manure + 25% rice mill waste (148.9 kg/ha).

K uptake in 2019 at 5 MAP was still highest in plots treated with 50% NPK + 50% rice mill waste (127.5 kg/ha), and it did not show any significant ($p<0.05$) difference from the combined plots and plots treated with 100% rice mill waste. It was significantly ($p<0.05$) different from other plots, with the control plot having the least value. At 8 MAP, plots treated with 50% NPK + 50% poultry manure still gave the K uptake of 158.7 kg/ha which did not show any significant difference with plots treated with 100% poultry manure. The increase in rhizome yield and uptake of plots treated with 50% NPK + 50% rice mill waste could be due to the synergistic effect of combination of organic and inorganic fertilizer that enhanced nutrient release and availability of improved potassium and other nutrients at the early stage of 5 months after planting, this agrees with Murwira and Kirchmann (1993) in their research findings that nutrient use efficiency of crops is increased through a combined application of organic manure and mineral fertilizer. Makinde *et al*. (2012) also reported that maize yields obtained from a mixture of organic and inorganic fertilizer application were significantly higher than yields from sole organic fertilizer application. There was a drastic increase in the yield and K uptake of ginger rhizome at 8 MAP with the combined and sole plots of poultry manure which is in agreement with the findings of Farhad *et al*. (2009) that poultry manure has been recognized as the most desirable source of organic matter which improves soil moisture and nutrient retention.

Table 3: Effect of different fertilizer sources on fresh ginger yield and potassium uptake at 5 and 8 months after planting (MAP) for 2018 and 2019 planting seasons

Treatment	**Fresh Yield (t ha^{-1})**				**K Uptake (kg ha^{-1})**			
	2018		**2019**		**2018**		**2019**	
	5 MAP	8 MAP	5 MAP	8 MAP	5 MAP	8 MAP	5 MAP	8 MAP
Control	24.4	26.8	25.7	28.3	46.2	66.9	49.9	70.0
100% NPK 15:15:15	43.3	42.7	44.3	39.8	93.9	123.5	93.0	107.8
100% Poultry Manure (PM)	35.1	47.5	32.8	50.0	90.8	150.2	76.7	151.5
100% Rice Mill Waste (RMW)	44.5	44.9	44.7	44.2	99.4	119.0	113.5	119.9
50% NPK + 50% PM	43.6	49.6	43.1	51.0	115.8	160.8	121.4	158.7
50% NPK + 50% RMW	49.6	46.7	47.5	44.4	128.5	141.6	127.5	122.5
50% NPK + 25% PM + 25% RMW	46.8	47.1	45.2	46.0	123.4	148.9	125.2	130.3
Mean	41.0	43.6	40.5	43.4	99.7	130.1	101.0	123.0
$LSD_{0.05}$	2.6	2.2	2.1	2.3	18.9	13.6	19.75	10.4

Table 4: Effect of treatments on soil forms of potassium at 5 and 8 months after planting (MAP) for 2018 planting seasons

	2018									
	5 MAP					8 MAP				
Treatments	Water Soluble K cmol/kg	Exch. K	Non Exch. K	Lattice K	Total K	Water Soluble K cmol/kg	Exch. K	Non Exch. K	Lattice K	Total K
Control	0.010	0.032	0.102	0.368	0.512	0.013	0.041	0.093	0.355	0.501
100% NPK 15:15:15	0.013	0.043	0.102	0.425	0.583	0.025	0.034	0.106	0.414	0.577
100% Poultry Manure (PM)	0.010	0.040	0.129	0.396	0.575	0.031	0.040	0.099	0.421	0.590
100% Rice Mill Waste (RMW)	0.021	0.038	0.105	0.423	0.586	0.027	0.044	0.128	0.438	0.638
50% NPK + 50% PM	0.019	0.041	0.139	0.405	0.605	0.031	0.050	0.104	0.414	0.598
50% NPK + 50% RMW	0.021	0.030	0.114	0.418	0.582	0.034	0.048	0.118	0.394	0.594
50% NPK + 25% PM + 25% RMW	0.020	0.039	0.127	0.404	0.590	0.032	0.049	0.111	0.400	0.592
Mean	0.016	0.038	0.117	0.406	0.576	0.028	0.044	0.108	0.405	0.584
$LSD_{0.05}$	0.003	0.005	0.008	0.012	0.025	0.002	0.004	0.007	0.024	0.018

3.4. Effect of Treatments on Soil Forms of Potassium at 5 and 8 Months after Planting for 2018 Planting Season

The forms of potassium as influenced by sole and combined use of NPK 15:15:15, poultry manure and rice mill waste at 5 and 8 months after planting for 2018 planting season is shown in Table 4.

Water soluble K in 2018 at 5 MAP under different treatments ranged from 0.010 to 0.021 cmol/kg with a mean of 0.016 cmol/kg. The highest water soluble K was obtained in plots treatment with 50% NPK + 50% rice mill waste and 100% rice mill waste (0.021 cmol/kg) and they did not show any significant ($p<0.05$) difference with plot treated with 50% NPK + 25% poultry manure + 25% rice mill waste (0.020 cmol/kg). At 8 MAP, water soluble K ranged from 0.013 to 0.034 cmol/kg with a mean of 0.028 cmol/kg. The highest water soluble K was obtained in 50% NPK + 50% rice mill waste (0.034 cmol/kg) and it was significantly higher than other treatments except the plot treated with 50% NPK + 25% poultry manure + 25% rice mill waste (0.032 cmol/kg). The increase in water soluble K of plots treated with any quantity of rice mill waste showed that there was a favourable change in soil conditions that took place through rice mill addition (Kher and Minhas, 1991). Srinivasarao and Takkar (1997) stated that soils with larger amounts of clay and organic matter showed greater amounts of water soluble K and ammonium acetate extractable K in both the top and sub soils.

Exchangeable K content in 2018 ranged from 0.030 to 0.043 cmol/kg with a mean of 0.038 cmol/kg and 0.034 to 0.050 cmol/kg with a mean of 0.044 cmol/kg at 5 and 8 MAP respectively. Addition of 100% NPK at 5 MAP gave the highest exchangeable K of 0.043 cmol/kg and it only showed a significant ($p<0.05$) difference with the control plot (0.032 cmol/kg) and with plot treated with 50% NPK + 50% rice mill waste and 100% rice mill waste (0.030 cmol/kg). At 8 MAP, addition of with 50% NPK + 50% poultry manure gave the highest exchangeable K of 0.050 cmol/kg and did not show any significant ($p<0.05$) difference with the combined plots. The exchangeable potassium was high because of high exchange sites offered for K fertilization and also addition of organic manures which might have enhanced the exchangeable K in solution phase. The results are on par with the findings of Divya *et al*. (2016).

Non exchangeable K content in 2018 varied from 0.102 to 0.139 cmol/kg with a mean of 0.117 cmol/kg and 0.093 to 0.128 cmol/kg with a mean of 0.108 cmol/kg at 5 and 8 MAP respectively. At 5 MAP, the highest non exchangeable K content was observed under 50% NPK + 50% poultry manure (0.139 cmol/kg) and it was significantly ($p<0.05$) different from other treatments. At 8 MAP, the highest non exchangeable K content was observed under 100% rice mill waste (0.128 cmol/kg) and it was significantly different from other treatments. The next was 50% NPK + 50% rice mill waste (0.118 cmol/kg) and it was significantly different from other treatments. The low non exchangeable K content noticed in some plots resulted from the release of potassium from reserve pool to compensate the loss of water soluble and exchangeable K by plant uptake. Similar findings were obtained by Kundu *et al*. (2014). In the soils, non exchangeable K (fixed K) is the principal source for supplying K to plants (Pasricha, 2002). The percent utilization of fixed K decreased as the level of added K increased in crop production (Ramanathan, 1978; Nagarajan, 1980).

Lattice K content in 2018 ranged from 0.368 to 0.425 cmol/kg with a mean of 0.406 cmol/kg and from 0.355 to 0.438 cmol/kg with a mean of 0.405 cmol/kg at 5 and 8 MAP respectively. The highest lattice potassium values were obtained from plots treated with 100% NPK (0.425 cmol/kg) and 100% rice mill waste (0.438 cmol/kg) and lowest in the control plot (0.368 and 0.355 cmol/kg) at 5 and 8 MAP. The low values of lattice K indicated that the soil was derived from a low potassium bearing clay minerals which retarded the lattice potassium content in the soil. With regards to the degree of weathering, lattice K content varied among the treatments. This result agrees with the findings of Divya *et al*. (2016).

Total K in 2018 ranged from 0.512 to 0.605 cmol/kg with a mean of 0.576 cmol/kg and 0.501 to 0.638 cmol/kg with a mean of 0.584 cmol/kg at 5 and 8 MAP respectively. Highest values of total K were obtained from plots treated with 50% NPK + 50% poultry manure (0.605 cmol/kg) and plot treated with 100% rice mill waste (0.638 cmol/kg) and lowest values were obtained from the control plot (0.512 and 0.501 cmol/kg) at 5 and 8 MAP respectively. The degree of weathering is important for the total content of potassium in soils. Depending on clay mineralogy, lattice K content and organic matter content, the total K content varied among the different treatments (Harsha and Jagadeesh 2017).

Effect of Treatments on Soil Forms of Potassium at 5 and 8 Months after Planting for 2019 Planting Season

The forms of potassium as influenced by sole and combined use of NPK 15:15:15, poultry manure and rice mill waste at 5 and 8 months after planting for 2019 planting season is shown in Table 5.

Water soluble K in 2019 ranged from 0.008 to 0.024 cmol/kg with a mean of 0.017 cmol/kg and 0.010 to 0.028 cmol/kg with a mean of 0.022 cmol/kg at 5 and 8 MAP respectively. At 5MAP, The highest value of water soluble K was obtained from plots treated with 100% rice mill waste (0.024 cmol/kg) and it did not show any significant ($p<0.05$) difference with the combined plots having rice mill waste in them. At 8 MAP, the highest value of water soluble K was obtained from plots treated with 50% NPK + 25% poultry manure + 25% rice mill waste (0.028 cmol/kg) and it did not show any significant ($p<0.05$) difference with 50% NPK + 50% poultry manure (0.027 cmol/kg) and100% (0.026 cmol/kg). Water soluble K had been reported to be a dominant fraction in the initial stage, while exchangeable and non exchangeable K contribute more in the later stages of crop growth (Subehia *et al.* 2003). The increase in water soluble K of plot treated with any quantity of rice mill waste at the earlier stage (5 MAP) showed that it had a high amount of organic matter content. Srinivasarao and Takkar (1997) stated that soils with larger amounts of organic matter showed greater amounts of water soluble and exchangeable K in both the surface and sub soils.

Exchangeable K content in 2019, ranged from 0.028 to 0.042 cmol/kg with a mean of 0.035 cmol/kg and 0.030 to 0.057 cmol/kg with a mean of 0.048 cmol/kg at 5 and 8 MAP respectively. At 5 MAP, the highest non exchangeable K were recorded in plots treated with 50% NPK + 50% poultry manure and 100% NPK (0.042 cmol/kg) and they did not show any statistical difference with plots treated with 50% NPK + 50% rice mill waste (0.057 cmol/kg) which did not show any significant ($p<0.05$) difference with most of the plots, except with the control plots (0.042 cmol/kg) and the plot treated 100% NPK (0.030 cmol/kg). The higher concentration of exchangeable K in the treated plots could be attributed to the addition of K through plant residues, manures and mineral fertilizers (Anil *et al.*, 2009). Furthermore, exchangeable K could give a better indication of the potential K supplying power of a soil and used for making fertilizer recommendation to the crops (Sharpley, 1989).

Non exchangeable K content in 2019 varied from 0.099 to 0.130 cmol/kg with a mean of 0.111 cmol/kg and 0.094 to 0.120 cmol/kg with a mean of 0.101 cmol/kg at 5 and 8 MAP respectively. At 5 MAP, plots treated with 50% NPK + 50% poultry manure had the highest K content of 0.130 cmol/kg and did not show any statistical difference with 100% poultry manure (0.122 cmol/kg) and 50% NPK +25% poultry manure + 25% rice mill waste (0.120 cmol/kg). At 8 MAP, plots treated with 50% NPK + 50% poultry manure still had the highest K content of 0.120 cmol/kg which was significantly ($p<0.05$) higher than other treatments. Non exchangeable K is not readily available to plants. However, it is in equilibrium with water soluble and exchangeable forms and consequently acts as an important reservoir of slowly available K (Perkins, 1973). The amount of non exchangeable K in the soil depends on the particle size distribution, types and quantities of clay minerals removal of K from minerals. Non exchangeable K level in soils, rich in K-bearing minerals in critical for a steady supply of K to plants.

Lattice K content in 2019 ranged from 0.355 to 0.438 cmol/kg with a mean of 0.395 cmol/kg and from 0.341 to 0.419 cmol/kg with a mean of 0.391 cmol/kg at 5 and 8 MAP respectively. The highest lattice potassium values were obtained from plots treated with 100% NPK (0.438 cmol/kg) and 50% NPK + 50% rice mill waste (0.419 cmol/kg) and lowest in the control plot (0.355 and 0.341 cmol/kg) at 5 and 8 MAP. The lattice K is made available to plants by weathering and the amount released depends upon in the soil texture and environmental conditions (Divya *et al.*, 2016; Grewal and Kanwar, 1973). The release and fixation of the lattice K is mainly governed by the type of clay minerals, soil reaction and the type of cation present.

Total K in 2019 ranged from 0.500 to 0.598 cmol/kg with a mean of 0.559 cmol/kg and 0.490 to 0.594 cmol/kg with a mean of 0.562 cmol/kg at 5 and 8 MAP respectively. Highest values of total K were obtained from plots treated with 50% NPK + 50% poultry manure (0.598 cmol/kg) and plot treated with 50% NPK + 50% poultry manure (0.594 cmol/kg) and lowest values were obtained from the control plot (0.500 and 0.490 cmol/kg) at 5 and 8 MAP respectively. Sharma *et al.,* (2006) found that total potassium was high in clay soil which shows that among the various particle size fractions, clay is a principal host of K in the soil. Total K is equally influenced by the nature of the lattice K content and organic matter content which agrees with the results of Hebsur and Gali (2011).

Table 5: Effect of treatments on soil forms of potassium at 5 and 8 months after planting (MAP) for 2019 planting season

Treatments	**2019**									
	5 MAP					8 MAP				
	Water Soluble K	Exch. K	Non Exch. K	Lattice K	Total K	Water Soluble K	Exch. K	Non Exch. K	Lattice K	Total K
	cmol/kg					cmol/kg				
Control	0.008	0.032	0.105	0.355	0.500	0.010	0.042	0.097	0.341	0.490
100% NPK 15:15:15	0.013	0.042	0.099	0.438	0.592	0.026	0.030	0.108	0.378	0.542
100% Poultry Manure (PM)	0.016	0.031	0.122	0.372	0.540	0.021	0.050	0.088	0.387	0.545
100% Rice Mill Waste (RMW)	0.024	0.034	0.101	0.423	0.581	0.022	0.051	0.103	0.409	0.583
50% NPK + 50% PM	0.018	0.042	0.130	0.409	0.598	0.027	0.052	0.120	0.395	0.594
50% NPK + 50% RMW	0.023	0.028	0.102	0.392	0.545	0.023	0.057	0.094	0.419	0.593
50% NPK + 25% PM + 25% RMW	0.020	0.039	0.120	0.376	0.555	0.028	0.052	0.099	0.410	0.589
Mean	0.017	0.035	0.111	0.395	0.559	0.022	0.048	0.101	0.391	0.562
$LSD_{0.05}$	0.005	0.008	0.015	0.023	0.024	0.003	0.009	0.006	0.022	0.020

3.5. Relationship among Potassium Forms in the Soil

Relationship among potassium forms in the soil at 5 and 8 MAP were correlated with each other (Table 6). In 2018, water soluble K at 5 MAP had a strong correlation with exchangeable K (r = 0.654**), non-exchangeable K (r = 0.793**) and total K (r = 0.633**) at 8 MAP and equally had a strong correlation with lattice K (r = 0.572**) and total K (r = 0.600**) at 5 MAP. Water soluble K at 8 MAP was strongly correlated with non exchangeable K (r = 0.618**), lattice K (r = 0.569**) and total K (r = 0.809**) at 5 MAP and it equally correlated with total K (r = 0.731**) at 8 MAP. Strong significant correlations between water soluble K and other forms of K indicate the faster rate of equilibrium among these K forms, similar inter relationships have been reported by Lakaria *et al.* (2012). Non exchangeable K at 8 MAP had a strong correlation with lattice K (r = 0.740**) at 5 MAP and total K (r = 0.551** and 0.744**) at 5 MAP and 8 MAP respectively. Lattice K and total K had positive and strong correlations between each other in the different months after planting. Significant correlation between different forms of K indicates the existence of dynamic equilibrium among different fractions. Therefore, it can be concluded that each fraction of potassium influences another directly or indirectly and hence all the forms are important in one way or the other (Mazumdar *et al*., 2014).

In 2019, water soluble K at 5 MAP had a strong correlation with exchangeable K (r = 0.564**), lattice K (r = 0.654**) and total K (r = 0.835**) at 8 MAP. Water soluble K at 8 MAP was strongly correlated with lattice K (r = 0.556** and 0.654**) and total K (r = 0.756** and 0.805**) at 5 and 8 MAP respectively. Exchangeable K at 5 MAP had a strong correlation with non exchangeable K (r = 0.686**) at 8 MAP and total K (r = 0.589**) at 5 MAP. At 8 MAP, it was strongly correlated with lattice K (r = 0.610**) and total K (r = 0.594**) at 8 MAP each. Non exchangeable K at 8 MAP, correlated significantly with lattice K (r = 0.594**) and total K (r = 0.685**) at 5 MAP. The lattice K at 5 MAP had a significant correlation with total K (r = 0.886**) at 5 MAP and at 8 MAP it correlated with total K (r = 0.903**) at 8 MAP. Therefore, all the forms are important in one way or the other for K availability in the soil (Lakaria *et al*., 2012 and Girija and Badrinath 1996).

3.6. Relationship among K Forms in Soil and K Uptake in Ginger Rhizome

Potassium uptake amounts by ginger rhizome at 5 and 8 MAP in 2018 and 2019 were correlated with the different forms of K (Table 7). At 5 MAP, water soluble K significantly correlated with ginger rhizome K uptake at 5 MAP in 2018 and at 5 and 8 MAP in 2019. At 8 MAP, water soluble K correlates significantly with the entire K uptake in both planting seasons. The exchangeable K at 8 MAP had significant correlation with K uptake at 5 and 8 MAP in 2018 and at 5 MAP in 2019. Non exchangeable K at 5 MAP correlates significantly with K uptake at 5 and 8 MAP in 2018 and at 8 MAP in 2019. At 8 MAP, it only correlates with K uptake at 5 MAP in 2018. Lattice K correlates significantly at 5 MAP with K uptake at 5 and 8 MAP in 2018 only and at 8 MAP it correlated with the K uptake at 8 MAP in 2018 and at 5 and 8 MAP in 2019. The total K at 5 and 8 MAP correlated significantly with K uptake at 5 and 8 MAP in both planting seasons.

The correlations between different forms of K and K uptake by ginger rhizomes may be a function of the concentration of forms of K in the soil (Singh and Singh, 1999 and Lakaria *et al*., 2012). The low correlation among exchangeable K at 5 MAP and non exchangeable K at 8 MAP indicates low K concentrations. The high correlations that existed in total K shows that ginger plant has a typical root characteristics that absorbs the reserve form of K from the soil (Katyal 1997).

Table 6: Relationship among different forms of potassium during the 2018 and 2019 planting seasons

Forms of potassium		Water soluble K		Exchangeable K		Non-Exch. K		Lattice K		Total K	
		5 MAP	8 MAP	5 MAP	8 MAP	5 MAP	8 MAP	5 MAP	8 MAP	5 MAP	8 MAP
						2018					
Water soluble K	5 MAP	1	0.586**	-0.127	0.654**	0.175	0.793**	0.572**	0.271	0.600**	0.633**
	8 MAP		1	0.174	0.381	0.618**	0.478*	0.569**	0.501*	0.809**	0.731**
Exchangeable K	5 MAP			1	-0.215	0.237	-0.027	0.310	0.444*	0.513*	0.288
	8 MAP				1	0.493*	0.273	-0.007	-0.041	0.315	0.283
Non exchangeable K	5 MAP					1	-0.144	-0.079	0.221	0.523*	0.298
	8 MAP						1	0.740**	0.429	0.551**	0.734**
Lattice K	5 MAP							1	0.640**	0.732**	0.749**
	8 MAP								1	0.565**	0.853**
Total K	5 MAP									1	0.771**
	8 MAP										1
						2019					
Water soluble K	5 MAP	1	0.538**	-0.042	0.564**	-0.001	-0.056	0.229	0.836**	0.320	0.835**
	8 MAP		1	0.510*	0.159	0.317	0.378	0.556**	0.654**	0.756**	0.805**
Exchangeable K	5 MAP			1	-0.425	0.196	0.686**	0.456*	0.012	0.589**	0.202
	8 MAP				1	0.296	-0.260	-0.231	0.610**	0.006	0.594**
Non exchangeable K	5 MAP					1	0.136	-0.281	0.086	0.098	0.270
	8 MAP						1	0.594**	-0.097	0.685**	0.207
Lattice K	5 MAP							1	0.232	0.886**	0.364
	8 MAP								1	0.406	0.903**
Total K	5 MAP									1	0.578**
	8 MAP										1

*Significant at 5% **Significant at 1%

4.0. Conclusion

In this study organic manure from animal (poultry manure) and plant (rice mill waste) sources has been found to be a good and viable replacement to chemical fertilizers in the production of ginger in this study area. There was a remarkable increase in crop yield and K uptake at the end of the experiment (at 8 MAP) with plots treated with 50% NPK + 50% poultry. All the forms of K are in dynamic equilibrium with one another because as one increases the other one decreases.

The combinations of 22.5 kg N/ha NPK15:15:15 + 22.5 kg N/ha poultry manure, 22.5 kg N/ha NPK15:15:15 + 22.5 kg N/ha rice mill waste, 22.5 kg N/ha NPK15:15:15 + 11.25 kg N/ha poultry manure + 11.25 kg N/ha rice mill waste and 45 kg N/ha poultry manure could be used for better soil properties and yield of ginger production in the study area.

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