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Response of Rice Beans (*Vigna umbellata*) to Different Phosphate Fertilizer Rates, Sources and Cropping Systems Established in Western Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Rice bean despite being an underutilized crop is a multipurpose legume crop with a potential of improving food security in western Kenya. Acidic soils with low phosphate and organic carbon levels limit its production. We investigated effects of four phosphate fertilizer levels and cropping systems on soils, agronomy and yield components of rice beans in Kaimosi Friends University College (KAFUCO), Rongo University and Siaya Agricultural Training Centre (ATC) farms in Vihiga, Migori, and Siaya Counties in western Kenya in the short rains of 2020 and long rains of 2021. The experiment consisted of twelve treatments replicated three times per site in a split-plot in a randomized complete block design (RCBD). The main plots comprised of three cropping systems

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(monocrop, conventional and MBILI (Managing Beneficial Interactions in Legume Intercrops)) while the subplots were made up of four phosphate fertilizer levels (without fertilizer (control), inorganic fertilizer (26P+22N kg ha^{-1}), pure organic (5P+22N kg ha^{-1}) and combined organic and inorganic fertilizers at half rates (15.5P+22N kg ha^{-1}). Soil analysis demonstrated that the soils had low P and % organic carbon in all the sites. There were no significant differences in Olsen P at p = .05 in all the sites. In Kaimosi, the average number of pods produced per plant was highest in the mono cropping systems (90) for treatments with mixed organic and inorganic phosphate fertilizers. Treatments with required phosphate fertilizers had the least number of days to flowering (about 75). However, days to 75% flowering in both seasons showed no significant differences in Kaimosi University and Siaya ATC farms with significant differences exhibited in Rongo University farm between the cropping systems at p= .05. The highest average rice beans yields were recorded in Rongo university farm (1.8 ton ha^{-1}) for the treatments with mixed organic and inorganic fertilizers in the mono cropping systems. The phosphorus agronomic efficiency was highest in treatments with pure organic matter. The partial factor productivity of phosphorus was highest in the mono cropping systems. There were significant differences in harvest indices, partial factor productivity and phosphorus agronomic efficiency in all the three sites 1.8 ton ha^{-1}. The study therefore has recommended that phosphate fertilizers are important in the rice beans production for improved yields to be realized.

Keywords: Acidic soils; agronomy; food security; yield components; underutilized crop.

1. INTRODUCTION

The soils of western Kenya are highly weathered Acrisols and Ferralsols (Aguyoh & Odhiambo, 2019, Owino et al., 2015). These soils have low nitrogen, phosphorus and organic matter leading to low crop yields (Ministry of Agriculture, 2014) attributed to denitrification, volatilization, soil erosion and run off as well as nutrient removal during crop harvest.

Legumes are characterized by high protein content and their ability to fix nitrogen into the soil. The common beans are the third most consumed crop in Kenya after maize and potato. The yields for common beans and cow peas produced in western Kenya continue to stagnate at 0.7 t ha^{-1} against a potential yield of 3 t ha^{-1} and 0.025-0.03 t ha^{-1} respectively (Onyango, 2017). These may be attributed to biotic and abiotic production constraints such as insect pests and diseases like anthracnose, angular leaf spot, halo light, rust and mosaic virus, drought and low soil fertility especially phosphorus deficiency (Makari, 2022). There is therefore a need to introduce biotic and abiotic stresses resistant crops like neglected legumes to help improve food security. Although exploring the potential of underutilized legumes has not been factored as a way of achieving sustainable development goals targets, cultivating these legumes seems to improve food security. Majority of these underutilized legume fall in the Genus Vigna, family Fabaceae. Rice beans are one such crop.

Rice beans (*Vigna umbellata* L.*)* are one of the neglected legumes originally cultivated in China, Nepal and some parts of Southeast Asia grown for food and fodder (Dahipahle et al., 2017). The crop is a nitrogen fixer hence an important component in soil fertility management and can also grow in different cropping systems (Khadka & Acharya, 2009). The crop is tolerant to drought and waterlog conditions (Saini et al., 2020). The seed yield of rice beans stands at 1.3- 2.8 t ha^{-1}in India, Zambia and Brazil (Dahipahle et al., 2017) and 1.0-1.2 t ha^{-1}in Nepal (Khadka & Acharya, 2009). Rice bean production has been limited by a lack of awareness about its nutritional and economic benefits. Rice bean's potential to become a successful crop has been recognized scientifically for several decades and it has historically spread from its original cultivation centers in the Himalayas, China, and Malaysia, to Korea, Japan, Mauritius, the Philippines, the United States, Brazil, and the West Indies (Tad-awan & Palaes, 2022). The legume is superior to the common legumes grown in western Kenya as it is tolerant to insect damage and frost and require relatively low inputs. Rice bean production can help bridge the gap between food demand and supply in Sub Saharan Africa (Andersen, 2012). The yield of rice beans has been declining in western Kenya, and currently just a handful farmers practice its cultivation. This is despite rice beans having high nutritional value (Onyancha et al., 2022).

Phosphorus is important for growth and development of roots of plants, the processes of energy transfer e.g. photosynthesis, cell division, cell respiration and biological nitrogen fixation. The nutrient is also necessary for seed formation and flowering processes. Phosphorus deficiency reduces the rates of these metabolic processes (Makari, 2022). Organic carbon encourage a diverse population of beneficial soil microorganisms by enhancing soil health, water-holding capacity, high cation exchange capacity, and low bulk density. However, the quality of these manures is insufficient to fulfill the nutritional requirements of the crops. It is essential for the improvement and maintenance of biological, physical, and chemical soil qualities that farmyard manure plays a part in (Zelalem, 2014).

Integrating legumes with cereals is meant to cushion the farmers against failure of the crops in the increasing changing climate. Multiple intercropping systems expand farmers cropping systems configurations baskets for improve household food security. In western Kenya, the conventional and MBILI intercropping systems are widely used (Kinyua et al., 2022).

Therefore, we aimed to explore the influence of different phosphate fertilizer sources on cropping systems and evaluated their impacts on soil parameters (P and %OC), crop phenology (days to 75% flowering and number of pods) and crop yields and yield components (harvest index, partial factor productivity and phosphorus agronomic efficiency).

2. MATERIALS AND METHODS

2.1 Study Sites

The study was conducted in western Kenya in three sites for two succesive seasons beginning with the short rainy season of September-December 2020 and ending with long rains of March to August 2021. The selected study sites fall under lowland and midland agro ecological zones where legumes commonly thrive in various cropping systems. Site one was KAFUCO (Kaimosi Friends University College) in Vihiga County. Kaimosi lies in an upper midland agro ecological zone with mean annual precipitation of 1400-2200 mm. It lies on latitude 0° 07’ 36” N, longitude 34°50’ 55” E at an altitude of 1679 m above sea level. The temperature ranges between 20-35°C. The soils are classified as Acrisols (Njogon et al., 2018). The second site was Rongo University, School of Agriculture Research and Teaching field in Migori County located between latitude 00º 49’ 33” S, longitude 034º 36’53” E at an altitude of 1522 m a.s.l in upper midland agro ecological zone. The mean annual precipitation of the area is 700-1800 mm with a mean annual temperature of 20.6°C. Soils in the region are classified as orthic Ferralsols (Aguyoh & Odhiambo, 2019). The third site was Siaya Agricultural Training College (ATC) farm in Siaya County and is located between latitude 00° 03’ 23” N and longitude 034° 17’ 25” E and at an altitudinal range of 1140 - 1500 m a.s.l. The region receives 1000-1750 mm per year of bimodal precipitation with temperature variations between 15 -30°C in a lower midland agro ecological zone. The soil type is Acrisols (Owino et al., 2015). All the three soils have been identified to be deficit in nitrogen, phosphorus and organic matter (Ministry of Agriculture, 2014). Initial soil test characteristics of the study area indicated that the soil organic carbon content was low in both the three sites i.e. 1.26% in Kaimosi, 1.980% in Rongo and 1.570% in Siaya. All the experimental sites had sufficient quantities of potassium and calcium. However, regular applications of both organic and inorganic fertilizers to replace nutrients that are lost through leaching, vaporization, and crop harvesting are needed to maintain acceptable levels of nutrients (Ministry of Agriculture, 2014).

The sites selection was influenced by farmers experience in rice beans production, availability of cropping systems, university and farmers willingness to set land for this research. Before establishing the experiment, all the three planting sites were placed in a one month natural fallow. Three randomized soil samples per plot were collected for initial site characterization from the fields within a plough layer of 10-20 cm. The samples obtained were taken to the University of Eldoret and Rongo University Soil Science Laboratory for testing for soil pH, phosphorus, nitrogen, potassium, organic carbon and calcium to establish their initial levels. This was important in calculating the quantities of fertilizer to be applied to the plots. The plots were prepared to fine-tilth using a hand hoe and boundaries marked with pegs. Furrows were dug based on spacing. After harvesting soil samples were collected and analyzed for organic carbon and phosphorus.

2.2 Treatments and Experimental Design

The experiment consisted of twelve treatments replicated three times per site following a split-plot in a randomized complete block design (RCBD). The main plots comprised three cropping systems, i.e. mono-cropping, conventional and MBILI systems. The sub-plots consisted of four phosphate fertilizer rates from inorganic and organic sources in the following combinations:

a) Control (No fertilizer applied)
b) Organic manure (5P+22N Kg ha^{-1})- Table 4 describes chemical analysis
c) Inorganic fertilizer (26P+22N Kg ha^{-1})
d) Combined organic and inorganic fertilizers (15.5P+22N kg ha^{-1})

These treatments were replicated three times under three cropping systems giving a total of 36 experimental units in the field (4T x 3S x 3R). The organic manure was sourced from Rongo University cowshed. The inorganic fertilizer sources for phosphorus were Triple Super phosphate, TSP and nitrogen was Calcium Ammonium Nitrate, CAN. The remaining 53 kg N ha^{-1} was applied during top dressing for maize crops only. This was done six weeks after planting in all three sites. The fertilizer treatments structure was based on recommended rates for legume production in Indo-China regions (26 kg P + 22 kg N ha^{-1}) and also the available data used in legume production in western Kenya (Khadka & Acharya, 2009). The rice beans seeds were locally provided by Rongo landrace. The maize hybrid used for intercrops (variety H513) was supplied by Kenya Seed Company, Eldoret.

2.3 Trial Management

The experimental plot size was 3.0 m ×3.0 m^2. Hybrid maize (variety H513) was planted at a spacing of 75 cm ×25 cm and rice beans at 30 cm ×10 cm. Monocropping had 600 stems per 9 m^2 with two seeds planted per hill which were later thinned to one seed per hill (300 stems per 9 m^2) translating into 333,333 stems ha^{-1} after 2 weeks of planting. In the conventional cropping system, maize spacing was 75 cm × 25 cm giving 96 stems per 9 m^2 with 2 seeds per hole with two maize seeds planted per hill and later thinned to one maize plant per hill translating into 53,333 stems ha^{-1}. This gave four lines of rice beans. A row of rice beans was planted with two seeds per hill between the maize rows (37.5 cm) with an intra-row spacing of 10 cm and later thinned to one seed per hole two weeks after planting. This gave a rice beans population of 133,333 stems ha-^{1}. In the MBILI system, each pair of maize lines was 30 cm apart and the distance between two neighboring maize pairs was 1 m. In the 1 m space between two pairs of maize, two rows of rice beans were planted. This gave four lines of rice beans. This gave a rice beans population of 133,333 stems ha-^{1}.

Fertilizers were applied using the banding method within the furrows. For maize under intercrops, 22 kg N ha-^{1} was applied during planting and the remaining 53 kg N ha-^{1} was applied six weeks after planting to give a total of 75 kg N ha^{-1}. The fertilizers were covered with a thin layer of soil before seed placement to prevent seed injury due to direct contact with fertilizer. A thin layer of soil was used to cover the seeds. Weeding was done after every two weeks to keep the plots free from weeds. Spraying for termites, stalk borers and other pests and diseases was done after every two weeks. For spraying, aqua wet 15SL, Prove 1.92 EC and Mistress Fungicide were used. Harvesting was done when 75% of the pods had turned brown in the fourth month after crop emergence. This was done in an effective harvest area (2.25 ×1.6 m^2) excluding border rows. To save seeds from shattering, the pods were collected during morning hours.

2.4 Data Collection on Soils, Agronomic, Yield and Yield Components

a) Available phosphorus was determined by Olsen's method, nitrogen concentration determined by colorimetric method and total organic carbon determined by Walkey and Black according to (Okalebo, Gathua and Paul, (Okalebo et al., 2002).
b) The number of days to flowering was determined by counting the number of days from sowing to the number of days when 75% of the rice beans produced flowers per plot in an effective harvest area (2.25 ×1.6 m^2) from eight plants within the four inner rows (Khadka, 2009.). An average per fertilizer level per cropping system was determined and presented.
c) Number of pods per plant was determined by counting the total number of pods from randomly selected eight plants within the four inner rows (effective harvest area) at physiological maturity per plot (Otieno et al., 2018). An average per fertilizer level per cropping system was determined and presented.
d) Grain yields. Harvesting took place in an effective harvest area of (2.25 ×1.6 m^2) excluding the crops on the border rows and edges. Both sub sample and total fresh weights were determined for rice beans for

each effective harvest area. The sub samples were then taken to University of Eldoret and Rongo University laboratories for drying. The sub samples were then weighed before threshing, after which the grains were separated from the rice beans stover. Their dry weight was then recorded. The grain moisture was adjusted to 13% after which the grain yields were expressed in kg ha $^{-1.}$ Grain yield was determined by taking the total sample fresh weight, multiplying it by the sub-sample dry weight, and then dividing this product by the sub-sample fresh weight. The resulting value was then multiplied by 10000 square meters and divided by 3.6 square meters to convert the yield to kg ha^{-1}.

e) Rice beans harvest index (%). This was calculated as a factor of grain yield in tons ha^{-1}/ biological yield in tons per ha × 100.

f) Phosphorus agronomic efficiency (AE) in kg kg^{-1} This was expressed as the difference between grain yield with phosphorus application and the yield without and the resultant product divided by the amount of phosphorus fertilizer. It is a measure of increase of grain yield per unit of phosphorus applied

$$\mathrm{AUE}\ \left(\mathrm{kg\ kg^{-1}}\right) = \frac{\mathrm{Y-Y_u}}{\mathrm{N_a}}$$

Where:

AUE, Agronomic Use Efficiency of phosphorus; Y, Dry matter yield of the fertilized plot in kg; Yu, Dry matter yield of the unfertilized plot in kg; Na, Quantity of nutrient applied (kg).

g) Partial factor productivity of phosphorus in kg kg^{-1} was determined by multiplying the grain yield in tons ha^{-1} by 1000 and the result divided by the amount of phosphorus applied per plot. It measures how productive a cropping system is compares to nutrient applied.

2.5 Statistical Analysis

The data was keyed in in excel sheet. It was then subjected to analysis of variance (ANOVA) to determine the effect of treatments by GEN STAT software (14th Ed.) at harvesting stage. The means were separated using least significant difference (LSD) and Fishers unprotected at 5% level of significance. The fixed factors were fertilizer levels and cropping systems and the random factors were study sites and season. The effects of fertilizer treatments, season, cropping systems, study sites and interactions were assessed. This was followed by descriptive analyses and the results presented in bar charts with error bars and tables.

3. RESULTS

3.1 Influence of Different Sources of Phosphate Fertilizers on Soil Phosphate Concentrations and Cropping Systems

It can be depicted from Table 1 that in Kaimosi Friends University, there were no significant differences in Olsen P and %N in the two seasons. However, % Carbon exhibited a significant difference at $p<0.05$ only during the short rains season. Furthermore, there were no significant differences in the Olsen P in both the short rains and long rains in Rongo University Agriculture farm and Siaya ATC as in Table 2 and Table 3, respectively. Table 5 elaborates that in Kaimosi Friends University and Rongo University farms, treatments with combined organic and inorganic fertilizers had highest phosphorus concentrations followed by those treated with pure inorganic fertilizers. However, treatments with only pure organic fertilizers had very low phosphorus concentration in the short rains. In the long rains, treatments with pure inorganic fertilizers produced the highest phosphorus concentrations in the two sites. However, in Siaya ATC farm, in the mono cropping and MBILI systems, treatments with mixed organic and inorganic fertilizers produced the highest phosphorus concentrations in the short rains season while in the conventional intercropping systems, treatments with pure inorganic fertilizers produced the highest phosphorus concentrations. However, in the long rains season, treatments with pure inorganic fertilizers produced the highest amounts of phosphate concentrations into the soil.

3.2 Influence of Different Sources of Fertilizers and Crop Arrangement on Number of Pods Per Plant in a Maize-rice Beans Intercropping Systems

Fig. 1 elaborates that, the number of pods produced per plant were significantly different during the short rains of 2020 but showed no significant differences during the long rains of 2021 in Kaimosi Friends University as per the cropping systems. The mono cropping with combined organic and inorganic fertilizers gave the highest number of pods in Kaimosi (92 pods per plant) whereas the lowest number of pods exhibited in the MBILI intercropping systems (75 pods per plant). However, in Rongo University and Siaya ATC, there were significant differences in both short and long rains concerning the number of pods produced within a cropping system. The highest number of pods was recorded in the mono cropping systems with 99 pods per plant and 95 pods per plant in a combined fertilizer treatment in the same sites respectively. The number of pods produced was highest in treatments with combined organic and inorganic fertilizers followed by those treatments with pure inorganic fertilizers in all the sites in all the seasons. However, treatments with pure organic fertilizers produced least number of pods as highlighted in Table 7.

3.3 Influence of Different Fertilizers Sources and Crop Arrangement on Number of Days to Flowering in a Maize-rice Beans Intercropping Systems

Fig. 2 denotes that that there were no significant differences in Kaimosi Friends University farm in regards to 75% flowering in both seasons. However, the shortest number of days to flowering was recorded in mono cropping systems (74 days) while the longest in the other cropping systems (103 days). However, in Rongo University farm and Siaya ATC there were significant differences on effect of fertilizer treatments on cropping systems at p = .05. Rongo University farm also gave the shortest maturity duration (67 days after planting). Treatments with mixed organic and inorganic fertilizers produced the least number of days to flowering followed by treatments with inorganic fertilizers in all the sites in all the seasons. However, treatments with organic fertilizers and those without fertilizers had the highest number of days to flowering as illustrated in Table 8.

3.4 Influence of Different Fertilizers Sources and Crop Arrangement on Grain Yields in Maize-rice Beans Intercropping Systems

As graphically illustrated by Fig. 3, there were significant differences due to yields in mono cropping as opposed to the intercropping systems in the two seasons where no significant differences between the three sites were detected at p = .05. The highest yields recorded 1.5 ton ha^{-1} at Kaimosi under the mono cropping systems under combined fertilizer treatment. In Rongo University farm the highest yields recorded 1.9 ton ha^{-1} during the long rains season. Siaya ATC yields stood at 1.4 ton ha^{-1} produced during the short rains season. However, the intercropping systems gave the lowest yields in all the three sites while MBILI recorded the lowest value ever. Treatments with mixed organic and inorganic fertilizers produced the highest yields followed by treatments with inorganic fertilizers in all the sites and in all the seasons. This was followed by treatments with pure organic fertilizers and treatments without fertilizers as depicted in Table 6.

3.5 Influence of Different Fertilizers Sources and Crop Arrangement on Phosphorus Agronomic Efficiency in Maize-rice Beans Intercropping Systems

There were significant differences in phosphorus agronomic efficiency when different sources of fertilizer and cropping systems were subjected to rice beans in all seasons and experimental sites (Fig. 4). Data released from Kaimosi Friends University and Rongo University farms reflected the highest Phosphorus agronomic efficiency of 67 kg kg^{-1} in comparison to those recorded (35 kg kg^{-1}) at Siaya ATC. It is important to note that these high PAEs were recorded in the mono cropping systems.

3.6 Influence of Different Fertilizers Sources and Crop Arrangement on Partial Factor Productivity of Phosphorus in a Maize-rice Beans Intercropping Systems

Fig. 5 elaborates that there were significant differences in partial factor productivity when different sources of fertilizer sources and cropping systems were subjected to rice beans in all the seasons and experimental sites. In Kaimosi Friends University, mono cropping systems gave the highest partial factor productivities i.e. 219.5 kg kg^{-1} in the short rains and 212.9 kg kg^{-1} in the long rains. In Rongo University farm the mono cropping systems also produced the highest partial factor productivity at 245.4 kg kg^{-1} in the short rains and 272.4 kg kg^{-1} during the long rains. In Siaya ATC farm, the mono cropping systems gave the highest partial factor productivity at 193.6 kg kg^{-1}during the short rainy season and 183.9 kg kg^{-1} during the long rainy season.

3.7 Influence of Different Fertilizers Sources and Crop Arrangement on Harvest Index in a Maize-rice Beans Intercropping Systems

Fig. 6, indicates that there were significant differences in crop harvest indices when different sources of fertilizer and cropping systems were subjected to rice beans in all seasons and experimental sites with mono cropping systems that gave the least harvest indices under all fertilizer levels. Conventional cropping systems gave the highest harvest indices in the rainy season. In Kaimosi Friends University and Rongo University farms the highest harvest index was 49.7 while Siaya ATC resulted in the highest harvest index accounted for 48 during the long rains in the conventional cropping system.

4. DISCUSSION

Influence of different fertilizers sources and crop arrangement on soil available phosphorus, nitrogen and organic carbon in western Kenya: Our study revealed that the soils of western Kenya are infertile hence lack essential nutrients. This also confirms other research scientists who found out that the major crop-limiting nutrients in western Kenya region are soil phosphorus, nitrogen and organic matter (Oloo, 2016, Peter et al., 2018, Owino et al., 2015). In the initial soil site characterization of western Kenya, the soil organic carbon content was low in both the three sites i.e. 1.26% in Kaimosi, 1.980% in Rongo and 1.570% in Siaya. Studies carried out by (Okalebo et al. 2002) have recommended that for improved soil fertility, the soil organic carbon should not be less than 4%. The low nutrient content is attributed to Acrisols and Ferralsols in the region which have undergone intense weathering (Owino et al., 2015). The results also indicated that there was low phosphorus and % nitrogen content in the region. For example, when the Olsen P (mg P kg^{-1}) is less than 10.0, it becomes deficient. The soil % nitrogen was also less than 0.25% in all three sites which are the critical point in the region (Ministry of Agriculture, 2014). The soils are also moderately acidic. These low-nutrient soils are due to continuous cropping without replenishing soils (Peter et al., 2018). All the experimental sites had sufficient quantities of potassium and calcium. However, regular applications of both organic and inorganic fertilizers to replace nutrients that are lost through leaching, vaporization, and crop harvesting are needed to maintain acceptable levels of nutrients (Ministry of Agriculture, 2014).

In Kaimosi University farm, there were no significant differences in P amounts in both the two seasons. This might be explained by the fact that samples of the soil were collected after harvest, and at this period most P could have been fixed as these soils are good in P fixing. However, there were significant differences in % OC for the MBILI intercrops for the short rainy season of 2020. This might be due to the fact that the farm was in use by agriculture students and the differences might be from previously used sources of fertilizers. This was confirmed by the data on the long rains which showed no significant differences. Similarly, data for Rongo university farm and Siaya (ATC Farm), indicated no significant differences in P and %OC for both seasons. These might be due to slow mineralization of organic matter as well as high P fixation. Additionally, it takes about 4-5 years of organic matter addition to the soil to significantly affect changes on the soil. The study was conducted for only two consecutive seasons which are considered short to impact soil properties. Similar results were recorded by (Kawaka et al. 2018) which also demonstrated slow decomposition of organic matter to affect a rapid significant change in soil properties within a short time. In addition, (Kisinyo et al., 2019), also demonstrated that soils of western Kenya have high P fixing capacities hence minimal soil P available at the end of the experiment.

Influence of different fertilizers sources and crop arrangement on agronomy of rice beans in maize-rice beans intercropping systems: This study has indicated that the number of pods per plant was highest in the mono cropping systems in all the three sites with MBILI intercropping producing the least number of pods. The mixing of organic and inorganic manure fertilizer treatment produced the highest number of pods in all the three cropping systems. This research therefore agrees with findings by Makari, (Makari, 2022) which indicated that in soils of low phosphorus levels there is need for application of phosphorus fertilizer for improved legume production. Phosphorus fasters flowering with an increment in the number of pods per plant through supporting energy transfer and root development and its deficiency caused delayed flowering while organic carbon improves soil health. Application of phosphorus fertilizers not only improve crop yields but also improves root nodulation and the content of phosphorus in leaves and stems as opposed to treatments with less or no phosphorus fertilizers. Rice beans are an N-fixing legume (fix approx. 80 kg ha^{-1} of nitrogen). When ploughed in, the roots promote soil structure and restore organic matter and nitrogen to the soil (Dahipahle et al., 2017).

Other researchers such as (Ndakidemi & Dakora, 2007) have also established that legumes grow poorly in fertilizer treatments where phosphate fertilizers were not applied before flowering. This had a resultant effect of decreased number of pods in such treatments. Tairo et al 2013 reported that improved yield with phosphorus fertilization could be associated with increased flowering and podding, improved micronutrient uptake, rapid growth of plants and rapid growth of crops since phosphorus is essential in initiation of flowering, transfer of energy, root nodulation, nitrogen fixation in the atmosphere, and development of fruits and formation of seeds in there research with soybeans and bio fertilizers. In the other intercropping systems, maize had faster growth rate, a greater height advantage, and a more extensive root system. As a result, the rice beans dominated lower parts of the intercrop canopy and got less photosynthetically active radiation (PAR). Rice beans being shade-sensitive therefore; produced less number of pods with increased days to 75% flowering. It has been shown that during the late flowering to mid-pod formation stages of growth, light levels are more critical than during the vegetative and late reproductive stages. As a result, any variations that result in a higher amount of PAR captured by the legume crop have the potential to raise the legume's production and the intercropping system's productivity (Matusso et al., 2014). The MBILI system enabled 20% more light to reach the legume component than the conventional intercropping systems in other researches.

Influence of different fertilizers sources and crop arrangement on yield and yield components of rice beans in maize-rice beans intercropping systems: In our study, the mono cropping systems produced the highest amount of grain yields than the other cropping systems. Within the mono cropping systems, treatments with combined organic and inorganic matter produced the highest yields in all the seasons and experimental sites. Treatment with the other cropping systems gave the least number of grain yields in all the seasons. The phosphorus agronomic efficiency was highest when the lower rates of phosphorus nutrients are used in all sites in all the seasons. The phosphorus partial factor productivity was highest in the mono cropping systems compared to the other cropping systems in all the study sites in both seasons with the treatment with pure organic matter providing the highest. In particular, the study established that treatments with organic matter had the highest partial factor productivity of phosphorus compared to other treatments. The mono cropping systems produced the least harvest indices in all the sites in all the seasons. It can be seen that fertilizer treatments with phosphate fertilizers and organic carbon produced the highest harvest indices in all the cropping systems. Selecting crops for greater biomass will lead to crops which take a long time to mature, with reduced harvest index and higher yields while selection for higher harvest index will lead to early maturing varieties with decreased yields (Makari, 2022). The intercropping systems had the highest harvest indices because they had the least total biomasses. The legume seed yields are a product of various plant growth factor expressed in pods per plant, seeds per pod and mean weight of the seeds which constitute the yield components. The largest seed yields are derived when all of these growth processes are maximized. The variations in yields produced are also attributed to the cropping systems used. In the mono cropping systems plant abiotic growth factors were at maximum hence high yields. Moreover, the system had the highest ricebeans plant density while the other cropping systems suppressed ricebeans development and its reproductive function. Similar results were also reported by Ndakidemi et al ,2007 who illustrated that in the cow pea- maize intercrops produced reduced yield of the legumes. At any level of phosphorus and organic carbon addition, the rice beans yields increased. This could be explained by the critical functions of phosphorus and organic carbon in the plant systems. There was variability in P use efficiencies and partial factor productivity between cropping systems. These results have also been reported by other researchers who studied intercropping systems. Inter cropping maize and legumes have been shown to improve soil fertility and food security in SSA. The land equivalent ratios of these systems are higher compared to the mono cropping systems. However, achieving high legume yields in these systems are hampered by competition for water, light and nutrients from the other components. Such competitions are ameliorated by choosing the most appropriate crop species, particular crop arrangement and improving fertilization to meet the crops plant demand. 33% reduction in pigeon pea yields and 22% yield reduction in beans has been reported by other researchers in maize- bean intercrops (Kinyua et al., 2022). In addition, it has been established that Bambara groundnuts exhibited strong response to P supply hence improved yields. Farmers could therefore benefit from the supplementary phosphorus supply (Gweyi-onyango et al., 2011, Tairo & Ndakidemi, 2013).

Table 1. Kaimosi friends university farm mean soil characteristics

		SR 2020			LR 2021		
Cropping systems	**Treatments**	**% C**	**OlsenP (mg P kg^{-1})**	**%N**	**% C**	**OlsenP (mg P kg^{1})**	**%N**
Mono	Inorg (26P+22N Kg ha^{-1})	1.6b	6.2a	0.1a	1.6a	8.3a	0.1a
Mono	Org (5P+22N Kg ha^{-1})	1.9b	5.9a	0.1a	2.3a	5.7a	0.1a
Mono	Mix (15.5P+22N Kg ha^{-1})	2.2b	7.0a	0.1a	2.0a	6.4a	0.1a
Conventional	Inorg (26P+22N Kg ha^{-1})	1.4b	6.3a	0.1a	1.7a	7.5a	0.1a
Conventional	Org (5P+22N Kg ha^{-1})	2.1b	5.6a	0.1a	2.0a	5.8a	0.1a
Conventional	Mix (15.5P+22N Kg ha^{-1})	1.8b	7.8a	0.1a	1.7a	6.8a	0.1a
MBILI	Inorg (26P+22N Kg ha^{-1})	1.4a	6.5a	0.1b	1.7a	8.6a	0.1a
MBILI	Org (5P+22N Kg ha^{-1})	1.6a	5.6a	0.1b	2.3a	5.9a	0.1a
MBILI	Mix (15.5P+22N Kg ha^{-1})	1.7a	6.9a	0.1b	1.8a	6.4a	0.2a
LSD(5%)		0.3	1.0	0.0	0.5	1.0	0.0

Mono=Pure rice beans; Conventional= one row maize, one row rice beans; MBILI=two rows maize, two rows rice beans; 0=No fertilizers; Inorg=Pure Inorganic fertilizers; Org=Pure organic fertilizers; Mix = Combined organic and inorganic fertilizers; SR=Short rains; CV=Co-efficient of variation; LSD =Least Significant different of means; LR= Long rains Means within a column followed by the same letters are not significantly different at p<0.05

Table 2. Rongo university farm mean soil characteristics

		SR 2020			LR 2021		
Cropping systems	**Treatment**	**% C**	**Olsen P (mg P kg^{-1})**	**%N**	**% C**	**Olsen P (mg P kg^{-1})**	**%N**
Mono	Inorg (26P+22N Kg ha-1)	2.0a	6.6a	0.1a	1.9a	8.9a	0.1a
Mono	Org (5P+22N Kg ha-1)	2.2a	6.0a	0.1a	2.1a	6.3a	0.1a
Mono	Mix (15.5P+22N Kg ha-1)	2.3a	8.0a	0.1a	2.4a	7.0a	0.1a
Conventional	Inorg (26P+22N Kg ha-1)	2.0a	6.6a	0.1a	1.9a	8.4a	0.1a
Conventional	Org (5P+22N Kg ha-1)	2.4a	6.0a	0.1a	2.0a	6.3a	0.1a
Conventional	Mix (15.5P+22N Kg ha-1)	2.4a	8.0a	0.1a	2.3a	6.9a	0.1a
MBILI	Inorg (26P+22N Kg ha-1)	2.0a	6.5a	0.1a	2.0a	7.9a	0.1a
MBILI	Org (5P+22N Kg ha-1)	2.2a	5.8a	0.1a	2.1a	6.1a	0.1a
MBILI	Mix (15.5P+22N Kg ha-1)	2.4a	6.5a	0.1a	2.4a	7.0a	0.1
LSD(5%)		0.2	1.2	0.0	0.3	1.2	0.0

Mono= Pure rice beans; Conventional= one row maize, one row rice beans; MBILI=two rows maize, two rows rice beans; 0=No fertilizers; Inorg=Pure Inorganic fertilizers; Org=Pure organic fertilizers; Mix = Combined organic and inorganic fertilizers; SR=Short rains; CV=Co-efficient of variation; LR= Long rains Means within a column followed by the same letters are not significantly different at p<5

Table 3. Siaya ATC mean soil characteristics

		SR 2020			LR 2021		
Cropping systems	**Treatment**	**% C**	**Olsen P (mg P kg^{-1})**	**%N**	**% C**	**Olsen P (mg P kg^{-1})**	**%N**
Mono	Inorg(26P+22N Kg ha-1)	1.8a	6.7b	0.1a	1.7a	8.7a	0.1a
Mono	Org (5P+22N Kg ha-1)	2.2a	6.3b	0.1a	2.3a	6.5a	0.1a
Mono	Mix(15.5P+22N Kg ha-1)	2.3a	7.4b	0.1a	2.6a	6.9a	0.1a
Conventional	0(No fertilizer)	1.6a	5.5a	0.1a	1.6a	5.7a	0.1a
Conventional	Inorg(26P+22N Kg ha-1)	1.9a	6.6a	0.1a	1.8a	8.5a	0.1a
Conventional	Org (5P+22N Kg ha-1)	2.1a	6.0a	0.1a	2.5a	6.2a	0.1a
Conventional	Mix(15.5P+22N Kg ha-1)	2.0a	6.3a	0.1a	2.3a	6.4a	0.1a
MBILI	0(No fertilizer)	1.6a	5.9ab	0.1a	1.6a	6.2a	0.1a
MBILI	Inorg(26P+22N Kg ha-1)	1.8a	6.5ab	0.1a	1.9a	7.3a	0.1a
MBILI	Org (5P+22N Kg ha-1)	2.4a	6.3ab	0.1a	2.3a	6.6a	0.1a
MBILI	Mix(15.5P+22N Kg ha-1)	1.9a	7.2ab	0.1a	2.1a	6.8a	0.2a
LSD(5%)		0.5	0.9	0.0	0.3	1.4	0.0

Mono=Pure rice beans; Conventional= one row maize, one row rice beans; MBILI=two rows maize, two rows rice beans; 0=No fertilizers; Inorg=Pure Inorganic fertilizers; Org=Pure organic fertilizers; Mix = Combined organic and inorganic fertilizers; SR=Short rains; CV=Co-efficient of variation; LR=Long rains Means within a column followed by the same letters are not significantly different at p<0.05

Table 4. Chemical composition of cow manure

MC%	%N	%P	% Ca	%Mg	%K	%C	pH	%Polyphenol	%Lignin
28	1.83	0.43	0.14	0.4	2.1	33	7.1	0.75	18

Analysis was done according to the manual developed by Okalebo et al. *(2002)*

Table 5. Comparison of organic and inorganic phosphate fertilizers sources and phosphorus concentrations

		Short rainy season			Long rainy season		
Cropping systems	**Treatments**	**Olsen P (mg P kg^{-1}) in Kaimosi**	**Olsen P (mg P kg^{-1}) in Rongo**	**Olsen P (mg P kg^{-1}) in Siaya**	**Olsen P (mg P kg^{-1}) in Kaimosi**	**Olsen P (mg P kg^{-1}) in Rongo**	**Olsen P (mg P kg^{-1}) in Siaya**
Mono	0(No fertilizer)	4.6	5.5	6.0	4.8	5.6	6.3
	Inorg(26P+22N Kg ha^{-1})	6.2	6.6	6.7	8.3	8.9	8.7
	Org (5P+22N Kg ha^{-1})	5.9	6.0	6.3	5.7	6.3	6.5
	Mix(15.5P+22N Kg ha^{-1})	7.0	8.0	7.4	6.4	7.0	6.9
Conventional	0(No fertilizer)	4.2	5.4	5.5	4.4	5.7	5.7
	Inorg(26P+22N Kg ha^{-1})	6.3	6.6	6.6	7.5	8.4	8.5
	Org (5P+22N Kg ha^{-1})	5.6	6.0	6.0	5.9	6.3	6.2
	Mix(15.5P+22N Kg ha^{-1})	7.8	8.0	6.3	6.8	6.9	6.4
MBILI	0(No fertilizer)	4.5	5.4	5.9	4.7	5.7	6.2
	Inorg(26P+22N Kg ha^{-1})	6.5	6.5	6.5	8.6	7.9	7.3
	Org (5P+22N Kg ha^{-1})	5.6	5.8	6.3	5.9	6.1	6.6
	Mix(15.5P+22N Kg ha^{-1})	6.9	6.5	7.2	6.4	7.0	6.8

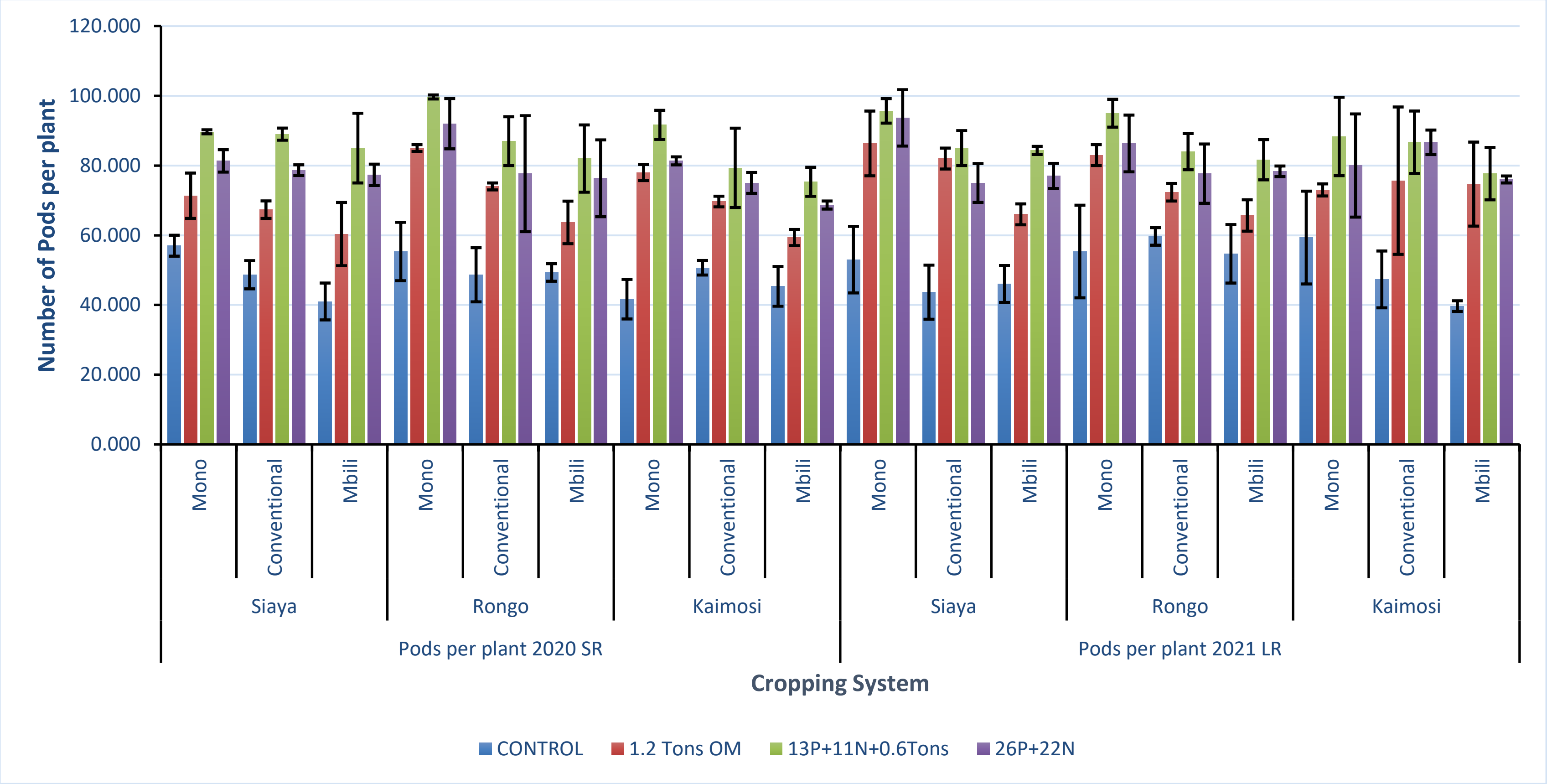

Fig. 1. Effect of Phosphate fertilizer treatments and cropping systems on number of pods per plant in western Kenya. Vertical bars represent standard deviation of the mean

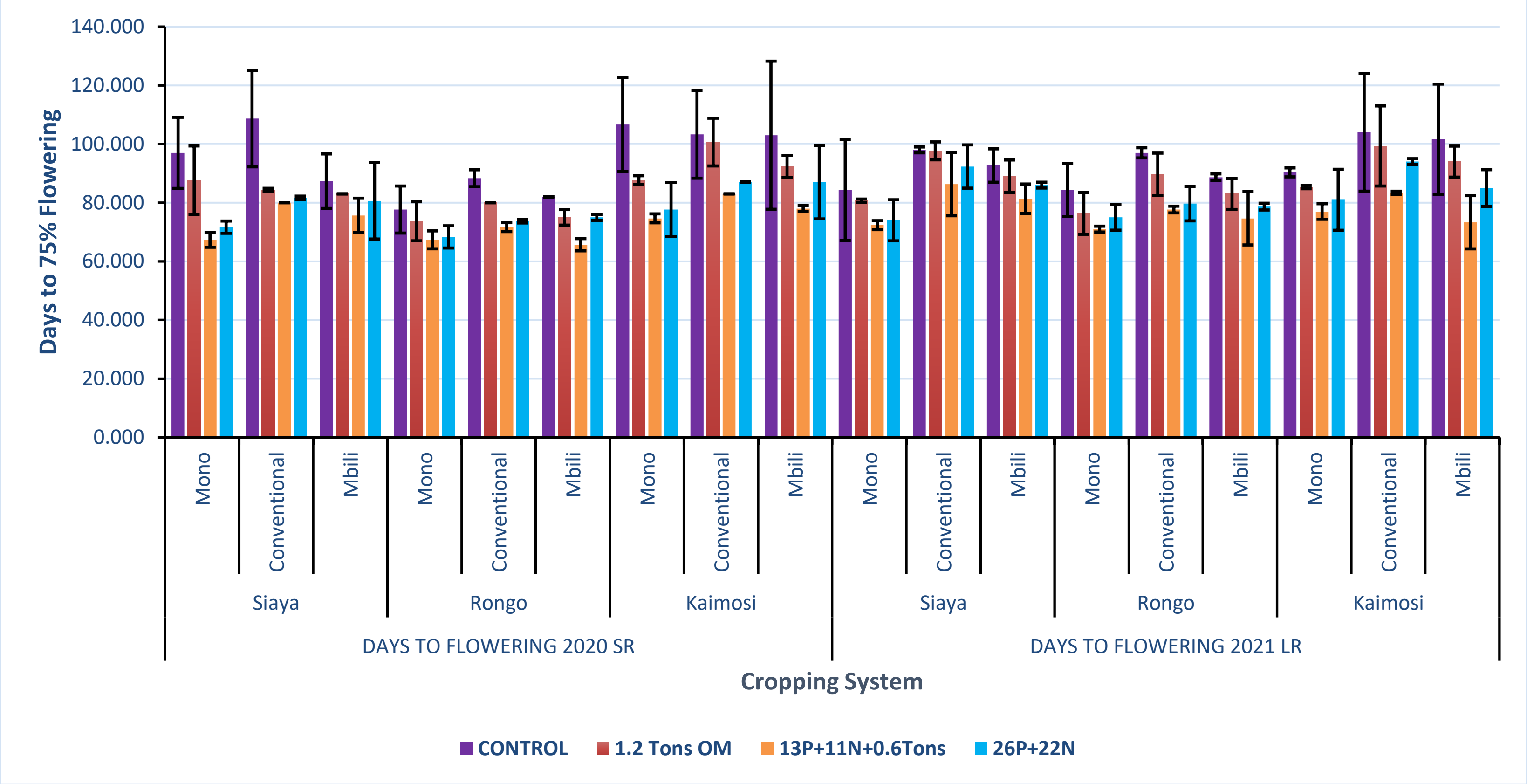

Fig. 2. Effect of Phosphate fertilizer treatments and cropping systems on number of days to 75% flowering in western Kenya. Vertical bars represent standard deviation of the mean

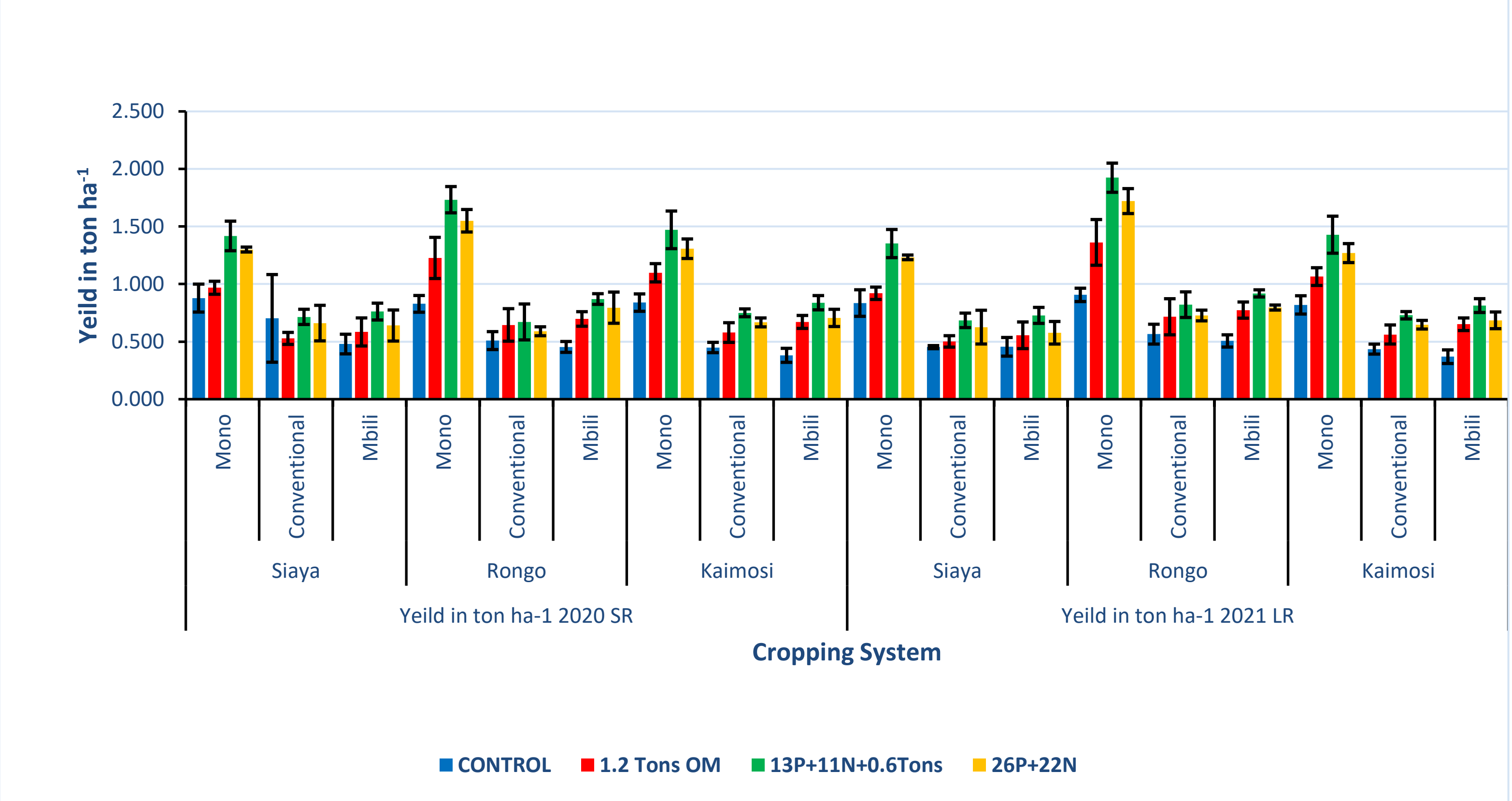

Fig. 3. Effect of Phosphate fertilizer treatments and cropping systems on grain yields in western Kenya. Vertical bars represent standard deviation of the mean

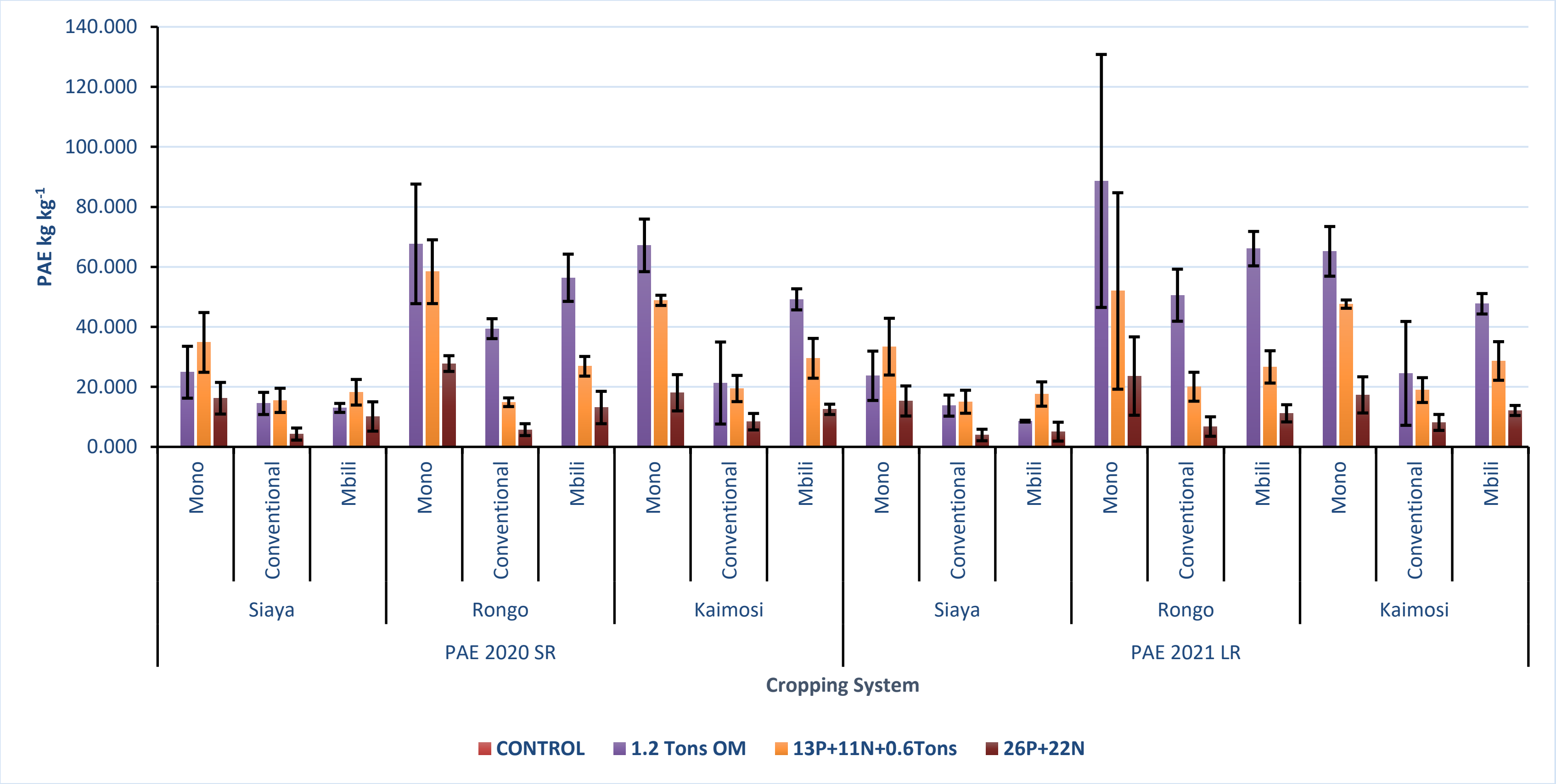

Fig. 4. Effect of Phosphate fertilizer treatments and cropping systems on phosphorus agronomic efficiency (PAE) in western Kenya. Vertical bars represent standard deviation of the mean

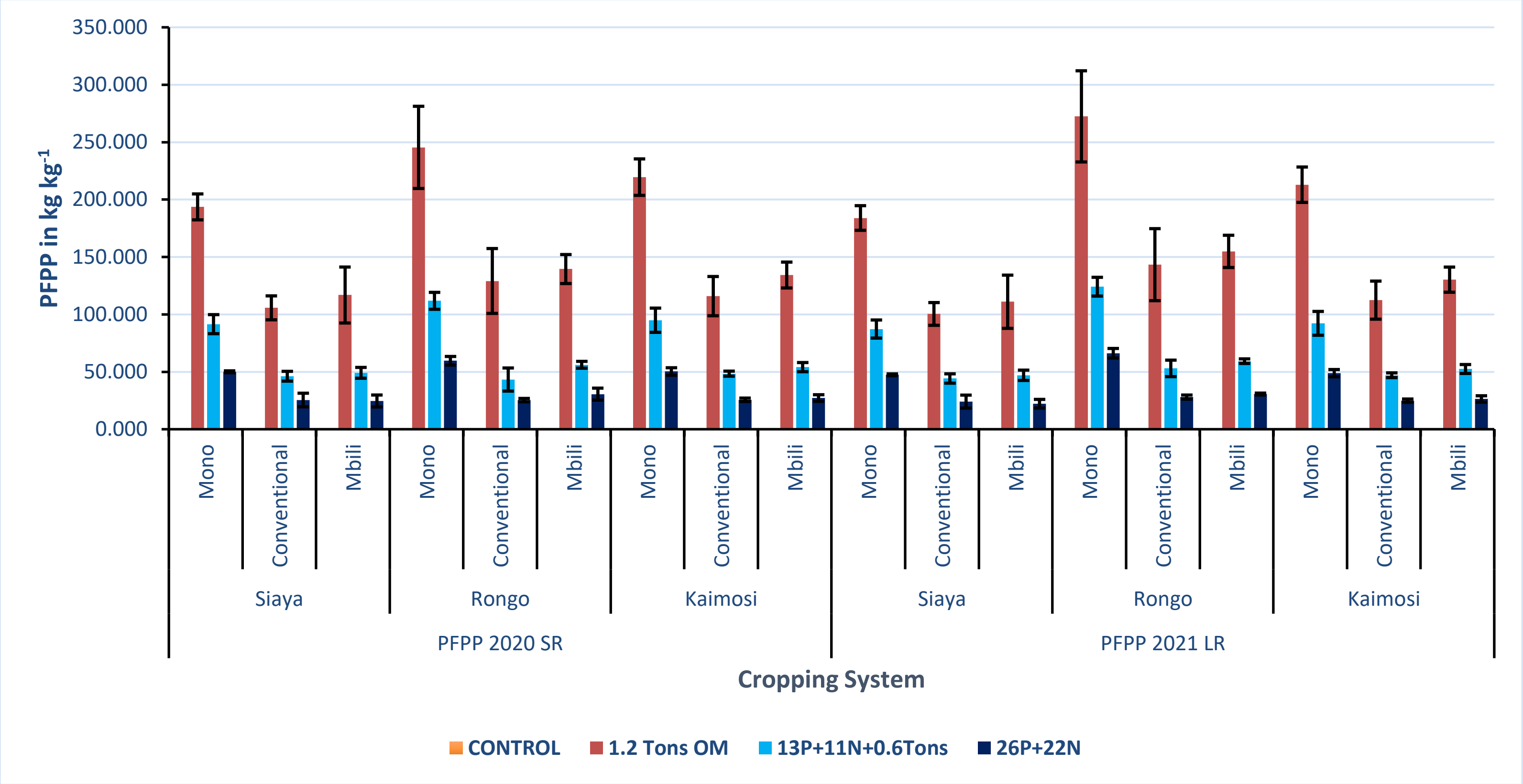

Fig. 5. Effect of Phosphate fertilizer treatments and cropping systems on partial factor productivity of phosphorus in western Kenya. Vertical bars represent standard deviation of the mean

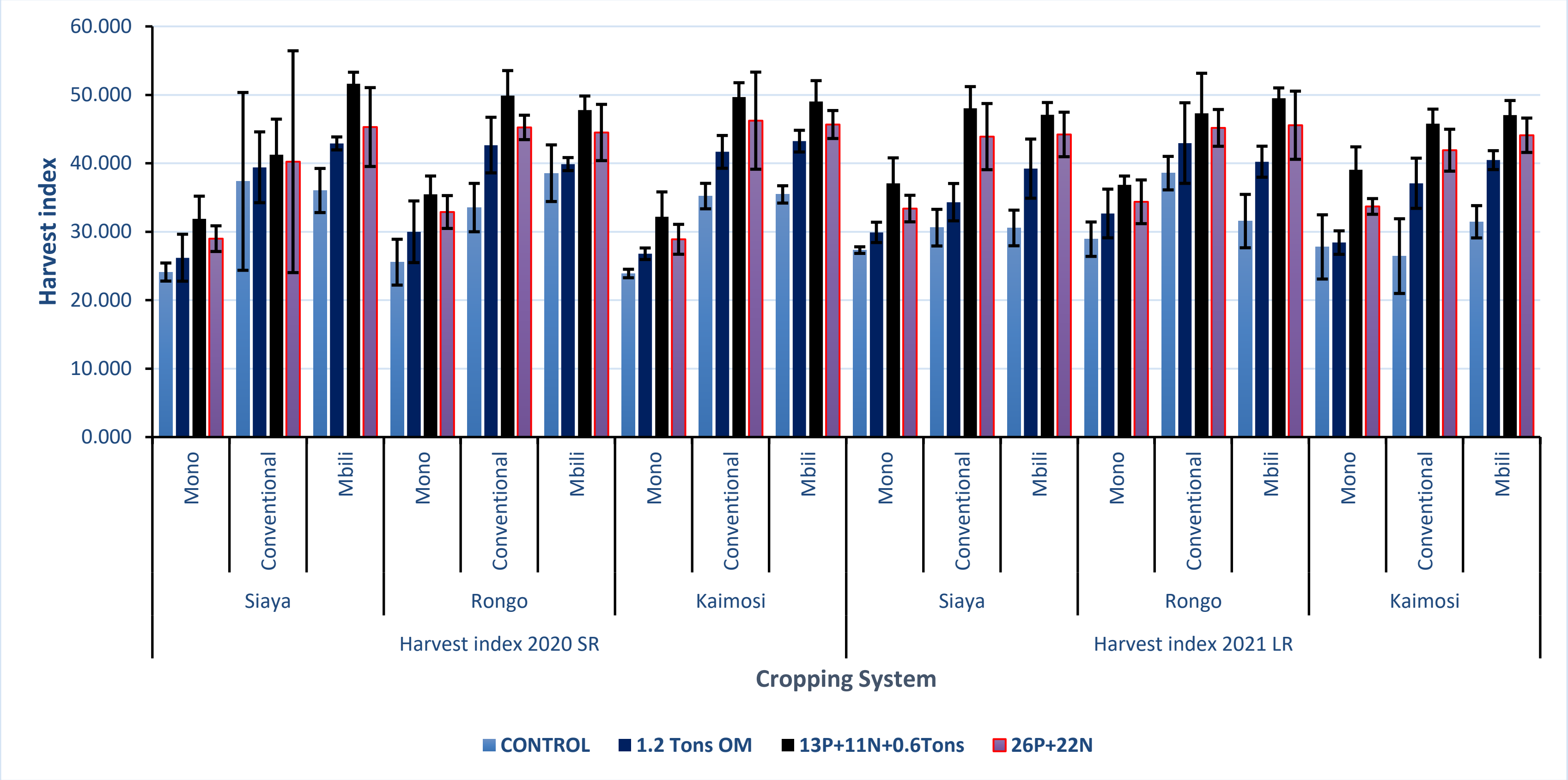

Fig. 6. Effect of Phosphate fertilizer treatments and cropping systems on harvest index in western Kenya. Vertical bars represent standard deviation of the mean

Table 6. Comparison of organic and inorganic phosphate fertilizers sources and rice beans yields

		Short rainy season			**Long rainy season**		
Cropping systems	**Treatments**	**Yields in ton ha^{-1} in Kaimosi**	**Yields in ton ha^{-1} in Rongo**	**Yields in ton ha^{-1} in Siaya**	**Yields in ton ha^{-1} in Kaimosi**	**Yields in ton ha^{-1} in Rongo**	**Yields in ton ha^{-1} in Siaya**
Mono	0(No fertilizer)	0.8	0.8	0.9	0.8	0.9	0.8
	Inorg(26P+22N Kg ha^{-1})	1.3	1.6	1.3	1.3	1.7	1.2
	Org (5P+22N Kg ha^{-1})	1.1	1.2	1.0	1.1	1.4	0.9
	Mix(15.5P+22N Kg ha^{-1})	1.5	1.7	1.4	1.4	1.9	1.4
Conventional	0(No fertilizer)	0.4	0.5	0.5	0.4	0.6	0.5
	Inorg(26P+22N Kg ha^{-1})	0.7	0.7	0.7	0.6	0.7	0.6
	Org (5P+22N Kg ha^{-1})	0.6	0.6	0.5	0.6	0.6	0.5
	Mix(15.5P+22N Kg ha^{-1})	0.8	0.7	0.7	0.7	0.8	0.7
MBILI	0(No fertilizer)	0.4	0.5	0.5	0.4	0.5	0.5
	Inorg(26P+22N Kg ha^{-1})	0.7	0.8	0.6	0.7	0.8	0.6
	Org (5P+22N Kg ha^{-1})	0.7	0.7	0.6	0.7	0.8	0.6
	Mix(15.5P+22N Kg ha^{-1})	0.8	0.9	0.8	0.8	0.9	0.7

Table 7. Comparison of organic and inorganic phosphate fertilizers sources and number of pods for the rice beans

		Short rainy season			**Long rainy season**		
Cropping systems	**Treatments**	**Number of pods in Kaimosi**	**Number of pods in Rongo**	**Number of pods in Siaya**	**Number of pods in Kaimosi**	**Number of pods in Rongo**	**Number of pods in Siaya**
Mono	0(No fertilizer)	42	55	57	59	55	53
	Inorg(26P+22N Kg ha^{-1})	81	92	81	80	86	94
	Org (5P+22N Kg ha^{-1})	78	85	71	73	83	86
	Mix(15.5P+22N Kg ha^{-1})	92	100	90	88	95	96
Conventional	0(No fertilizer)	51	49	49	47	60	44
	Inorg(26P+22N Kg ha^{-1})	75	78	79	87	78	75
	Org (5P+22N Kg ha^{-1})	70	74	67	76	72	82
	Mix(15.5P+22N Kg ha^{-1})	79	87	89	87	84	85
MBILI	0(No fertilizer)	45	49	41	40	55	46
	Inorg(26P+22N Kg ha^{-1})	69	76	77	76	78	77
	Org (5P+22N Kg ha^{-1})	59	64	60	75	66	66
	Mix(15.5P+22N Kg ha^{-1})	75	82	85	78	82	84

Table 8. Comparison of organic and inorganic phosphate fertilizers sources and number of days to 75% flowering for the rice beans

		Short rainy season			Long rainy season		
Cropping systems	**Treatments**	**Number of days to 75% flowering in Kaimosi**	**Number of days to 75% flowering in Rongo**	**Number of days to 75% flowering in Siaya**	**Number of days to 75% flowering in Kaimosi**	**Number of days to 75% flowering in Rongo**	**Number of days to 75% flowering in Siaya**
Mono	0(No fertilizer)	107	78	97	90	84	84
	Inorg(26P+22N Kg ha^{-1})	78	68	72	81	75	74
	Org (5P+22N Kg ha^{-1})	88	74	88	85	76	81
	Mix(15.5P+22N Kg ha^{-1})	75	67	67	77	71	72
Conventional	0(No fertilizer)	103	88	109	104	97	98
	Inorg(26P+22N Kg ha^{-1})	87	74	82	94	80	92
	Org (5P+22N Kg ha^{-1})	101	80	84	99	90	98
	Mix(15.5P+22N Kg ha^{-1})	83	72	80	83	78	86
MBILI	0(No fertilizer)	103	82	87	102	89	93
	Inorg(26P+22N Kg ha^{-1})	87	75	81	85	79	86
	Org (5P+22N Kg ha^{-1})	92	75	83	94	83	89
	Mix(15.5P+22N Kg ha^{-1})	78	7	76	73	75	81

5. CONCLUSION

The study has elaborated that rice beans production require phosphate fertilization in western Kenya. A combination of both organic and inorganic fertilizers is necessary for the improvement of its growth and development. The growth performance (days to 75% flowering and number of pods per plant) and yield components (yield, harvest index, agronomic efficiency, and partial factor productivity) of rice beans are influenced by phosphorus rates and forms. Since the soils of western Kenya are infertile, farmers are advised to apply phosphate fertilizers to improve their crop yields. Organic matter is also essential in crop development. The findings have stated the critical roles played by phosphate fertilizers and organic carbon in rice beans production. Farmers are therefore urged to try these underutilized crops whose growth characteristics can adapt and resilient to the ever changing climate in western Kenya.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

DATA AVAILABILITY STATEMENT

The data which was generated for this study will only be availed on request.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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