# Effects of potato-legume intercropping and variety on potato performance in different agroecosystems of Kenya

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## ABSTRACT

Potato is an increasingly important crop in Kenya, but potato farmers' yields, resource use efficiency and resilience to climate change are often below their potential due to poor or variable access to quality seed, fertilizer, irrigation, and best management practices (BMP) adapted for their agroecological zone. Farmers in Kenya need low risk and cost-effective strategies to increase system productivity and resilience that work independently of and additively with access to other technologies while mitigating the negative effects of extreme weather events and shifts in precipitation. Both potato intercropping systems and climate-smart potato varieties have shown potential to satisfy these needs. This study sought to assess the performance of a new climate smart potato variety in various potato intercropping systems to identify potential synergies between these two climate smart strategies across agroecozones. This study measured the yield, nutrient uptake, soil moisture, leaf area index, and yield of the conventional potato variety Shangi and the new climate smart potato variety Unica in a monocrop and intercropped with two legumes (lablab bean or dolichos (*Lablab purpureous) and* lima bean (*Phaseolus lunatus*)) at 4 sites representing different agroecozones where potatoes are grown across Kenya. The yield, LAI, soil moisture and nutrient uptake for Unica were significantly higher in almost all treatments at all sites when compared to their respective Shangi treatments. These metrics were also highest in potato monocropped treatments when compared to intercropped treatments at all sites except Kabete, the lower highlands agroecozone, where the Potato + Lablab intercropped treatment had the highest per plant potato yield and NPK uptake. No synergies between intercropping treatments and potato variety were identified as statistically significant.

## INTRODUCTION

### Background and Rationale

After maize, potato is the most important crop for food security and the fastest expanding food crop in Kenya (FAO, 2013). More than 800,000 smallholder farmers in Kenya, mainly in medium to high rainfall and altitude areas rely on potato as their main crop (FAO, 2013). Potato is valued as a reliable food security crop because it yields more calories and nutrients per unit of water, land, and time than most other major crops (FAO, 2013; Schulte-Geldermann, 2013). Potato contains high levels of vitamin C, vitamin B, potassium, magnesium, zinc, iron, folic acid, carbohydrates, and protein (Low, 2015). Potatoes are largely traded nationally, making them far less susceptible to global market shocks and price speculation experienced by more widely traded staple crops. As such, they contribute to a more stable food system and predictable source of income (FAO, 2008; Kleinmechter, 2015). Potato also provides significant income opportunities for smallholder farmers through the growing Kenyan processed potato industry. The high demand for fast foods in East Africa is a major factor contributing to the growing Kenyan processed potato industry which is in turn increasing demand for processing quality potatoes (Fanzo, 2012).

To sustain a growing demand for potatoes, potato farming in Kenya needs to intensify production but there are many challenges inhibiting this goal. Increasing population density and decreasing available arable land are leading to an increase of potato cultivation on marginal sloped lands. Soil erosion, climate warming, low accessibility of fertilizer, irrigation, and clean seed, and poor pest, soil, and disease management also hamper needed yield improvements and minimize the effectiveness and adoption of new technologies and strategies (Muthoni, 2013).

Testing and potentially increasing the implementation of optimal intercropping systems for each agroecosystem in potato producing regions is one strategy the International Potato Center (CIP) is pursuing that shows potential to assist in the intensification of Kenya's potato industry while increasing resilience to climate change and soil erosion (Nyawade, 2016; Sharaiha, 2013). One intercropping system identified is a potato/legume system planted in a 2 by 2 row pattern pattern known as the "mbili system" in Kenya (Mucheru-Muna et al., 2010). Another strategy is the creation and introduction of new climate smart potato varieties bred for heat, disease, and drought resistance. Unica, one such potato variety, was released in Kenya in 2016. Despite the potential of new climate smart potato varieties and intercropping systems, farm adoption in Kenya remains low (Schulte-Geldermann, 2013). As of 2014 only 5.5% of Kenyan farmers who grew potatoes, grew them in an intercrop (Muthoni, 2013). In 2005 in Nyandarua and Meru, two major potato growing regions in Kenya, it was estimated 14% of farmer's intercrop potatoes (Kaguongo, 2008). While 53% of Kenyan potato farmers have adopted improved varieties compared to 77.8% adoption rate of Ugandan potato farmers (Kaguongo, 2008).

One way to increase the adoption of agricultural management strategies and technologies is to pair together strategies and technologies which have an additive synergistic effect (Tekewold, 2016). Combining intercropping and new climate smart potato varieties has potential synergistic effects. By modifying crop environment and resource use in time and space, specific potato/legume intercropping systems can increase the relative crop yields, reduce erosion, reduce soil temperature, increase water use efficiency, and nitrogen use efficiency (Burke 2016; Nyawade, 2016; Sharaiha, 2013). Unica yields very well relative to other potato varieties under ideal conditions and conditions of drought and heat stress (Saravia, 2016). The performance of potato/legume intercropping systems, however, depends greatly on the type of legume, the potato variety, and the planting pattern used, as well as the agroecosystem in which it is grown (Gitari, 2015; Burke 2016; Sharaiha, 2013). One potential synergy between these traits could be seen in agroecozones where higher than ideal soil temperatures for potato production causes yield loss. Soil temperature dramatically affects potato yield (Midmore, 1990; Midmore 1987; Sharaiha, 2013). One potential synergy could be the pairing of soil temperature reduction observed from potato/legume intercropping and the increased tolerance to high soil temperature in Unica allowing for greater resilience against heat stress than the implementation of either of these practices in isolation. This synergy could represent and additive interaction if temperature is a large enough factor decreasing potato yield as the negative effects of increases in soil temperature on yield tend to be exponential (Midmore, 1990; Midmore 1987; Hancock, 2013).

More information is needed to assess the potential of various potato/legume intercropping systems to increase farmers' productivity in various agroecosystem in Kenya and to see if these intercropping systems have a synergistic affect when packaged with climate-smart varieties. Greater understanding of the relative contribution of specific intercropping systems and crop varieties in different agroecosystems on yield, nutrient uptake, and soil microenvironment will help inform intensification strategies and their potential to improve small-holder potato farmers resilience to climate change. Testing new germplasm in improved systems is critical to reconcile advances in breeding with agronomy and provide holistic integrated solutions to local growers (Teklewold, 2016).

Climate Smart Potato Varieties and Intercropping in Africa/Kenya

Improved varieties are an effective tool to increase the intensification of agriculture (Pretty, 2011). The definition of an improved variety is a variety originating from trials conducted by public or private research and selected and adopted by farmers because of their superior qualities for less than 35 years. Climate-smart varieties are improved varieties whose selection has been informed by climate's potential present and future impacts on agriculture (Pretty, 2011; Teklewold, 2016). Technologies of improved cropping systems and climate-smart cropping systems are similarly differentiated. The climate-smart goals are to first increase agricultural productivity in order to increase income and food security; second to strengthen farmers' resilience to climate change; and, third, to decrease greenhouse gas emissions and increase carbon sinks (Teklewold, 2016). The relative priority of these objectives depends on location. Smallholder farming systems in developing countries, for example, would tend to put the greatest emphasis on productivity and resilience due to food security being a critical concern, while highly intensive farms in developed countries priority goals might be to decrease greenhouse gas emission and increase carbon sinks (Campbell, 2014).

The adoption of climate-smart agricultural strategies in Kenya's potato industry are becoming more pertinent as more information is gathered on its current and projected climate and land availability. Total potato production in Kenya increased 9% from 2009 to 2013 from 2.3 to 2.9 megatons mostly due to potato cropping land area increasing 12.3% in the same period (FAO, 2013). This expansion has caused potato to be grown in untraditional areas that are warmer, drier, and lower altitude (Low, 2007 ; Multhoni, 2013). Expansion of cultivated agricultural land has caused a reduction in available arable land as well as the increase in cultivation of marginal land in traditional potato growing areas in the highly populated highland regions in Kenya (Muthoni, 2013; Vanlauwe, 2011). Globally, Hinmans (2003) predicted that climate change threatens to decrease potato yields by up to 32% by 2070 if nothing is done due to increased temperatures, higher evapotranspiration rates, and more erratic rainfall. These trends are already confirmed by meteorological data in SSA, indicating that the region is at a greater risk of short-term crop failures as well as long-term production declines (Ngigi 2009; Lasco et al. 2014). Climate-smart potato varieties and cropping systems offer the potential to increase resilience to these trends through increasing heat and drought tolerance while increasing yields and minimizing farmers' emission of greenhouse gases (Asfaw, 2015).

Synergies between Potato Variety and Intercropping Systems affecting Yield

The impact of and interaction between combining climate-smart varieties and intercropping system designs is largely unknown. There is evidence that combining multiple climate-smart practices and technologies can have additive effects, leading to greater overall gains in yield, profit, and technology adoption than adopting practices and technologies in isolation, but this is technology and location specific (Teklewold, 2016). Teklewold (2016) found that when Ethiopian farmers adopted recommended water management, improved variety, and fertilizer together the relative benefit to their net income was significantly greater then adopting said practices in isolation. However, farmers were far less likely to adopt any strategy when there was high rainfall variability. Packaging strategies with a positive additive effect is more effective to improving farm's net income than piecemeal approaches when there is a low enough risk of crop failure (Teklewold, 2016).

The individual impacts on yield of climate smart varieties and potato intercropping systems are better known. Average potato yields in SSA are 7.8 tons/ha (FAO, 2012 ; Schulte-Geldermann, 2013). Average Kenyan yields depending on the source were either 14 tons/ha or 10 tons/ha in 2013 (FAO, 2016; FAO, 2013). There is great potential for yield growth. Examples of this potential are observations of yields of 25 tons/ha being attained by farmers with high technology and best management practice adoption whose neighbors with low technology and best management practice adoption are attaining yields of 5-6 tons/ha (FAO, 2012 ; Schulte-Geldermann, 2013). According to Kleinmechter's (2015) ex ante analysis, the effects of improved potato varieties in East and Central African countries has contributed to a 0.5% to 8.5% increase in the potato supply. The use of improved varieties when compared to local varieties in Kenya has an average yield gain of 0.97 tons/ha (Kaguongo, 2008). Improved varieties have also been shown to increase resilience against drought and heat stress. This benefit, however, is limited as even potato yields of new improved drought and heat resistant varieties, including Unica, were diminished by 50% when experiencing drought 60 days after planting compared to yields of the same varieties kept a healthy soil moisture content of 20% (Saravia, 2016).

Evidence for the level of benefit to yield of intercropping potatoes with legumes in the Kenyan highlands is less clear due to the interactions of many variables which effect the system, including legume variety, planting pattern, and plant spacing. Two crops that complement each other with the least amount of competition in growth habits such as height, leaf cover, and root growth when grown together can give greater yield stability over time. (Keerio, 1986; Bhatti, 2006; Chandra, 2013; Burke, 2016) The Sharaiha (2013) study found that when growing two potato varieties in a two by two row intercropping pattern with common bean, potato had a yield increase of 63.9% and 70.7% and bean had a yield increase of 70.9% and 57% when compared to the yield of sole cropping treatments using the same relative amount of land compared to the land used for each crop in the intercropping treatment. Though when potato varieties were in a two rows of potato by one row of common beans intercropping pattern, all yields were significantly reduced, although they were still significantly higher than in the potato and bean sole cropping systems (Sharaiha, 2013). When One Acre Fund intercropped corn with potatoes and beans in Rwanda they found an increase in the Land Equivalence Ratio (LER) of 54% and 36% respectively (One Acre Fund, 2016).  LER is "the ratio of the area under sole cropping to the area under intercropping needed to give equal amounts of yield at the same management level. It is the sum of the fractions of the intercropped yields divided by the sole-crop yields" (Burke; 2016). A CIP study found that intercropping potatoes with lablab in a one by one row pattern at a field station in Nairobi, Kenya had a significantly higher LER when compared to the monocropped potato treatment during the short rainy season 2014 while having a significantly lower LER during the 2015 long rainy season. While intercropping potato with garden pea or climbing bean had a significantly lower LER when compared to sole potato during both seasons (Gitari, 2015).

Potato Variety and Intercropping Systems' Effect on Nutrient Use

The most common definition of nutrient use efficiency is the yield of a crop per unit of available nutrient (Swain, 2014). Nutrient use efficiency (NUE) of plants depends on the ability of the crop to effectively use nutrients applied as fertilizer as well as the capability of the soil to effectively supply nutrients (Baligar, 2001). A plant's ability to use nutrients is affected by its genetics and response to environmental variables such as disease, insects, allelopathy, root microbes, solar radiation, water availability and temperature (Fageria, 2005). A soils ability to supply nutrients is affected by chemical factors such as elemental deficiencies, low organic matter, nutrient fixation, and physical factors such as high bulk density, poor structure, low water holding capacity and leaching (Baligar, 1997, Fischer, 1998; Baligar et al., 2001). Intercropping and crop variety can significantly affect NUE (Fageria, 2005; Kouret al., 2014, Nyawade, 2015).

Reducing optimal fertilizer input via breeding plants with increased NUE has become a goal in many breeding programs (Hirel, 2007). In a study assessing interactions between potato varieties, fertilization practices, and nitrogen use efficiency, Swain (2014) found potato varieties Sarpo Mira and Sante had a difference of 7 kg dry matter/kg N fertilization (Swain, 2014). Dry matter accumulation, a critical factor of NUE, was significantly affected by total light interception, thus late maturing potato varieties have a higher NUE (Swain, 2014). Water availability and utilization ability are also correlated to NUE, thus drought tolerant varieties often have higher NUE when tested in situations with less than optimal soil moisture during an extended part of the growing season (Saravia, 2016). When Unica was tested against two other drought tolerant early maturing varieties, it was found to have the highest nitrogen use efficiency under all treatment conditions (low water, high water, low fertilizer, and high fertilizer) (Saravia, 2016).

The potential of different potato intercropping systems to increase NUE has also been measured in a few studies. Potato is a shallow rooted crop with about 85% of its roots found in between 0 and 40cm in the soil. (Gitari, 2015; Burke, 2016). Potato requires a great amount of soil disturbance at planting and harvesting leading to high potential rates of runoff and erosion. These two attributes limit potato NUE (Burke, 2016; Nyawade, 2015). When potatoes are paired with deep rooted, high ground cover crops, nutrient uptake is significantly increased while nutrient runoff is significantly decreased. When potatoes were intercropped with deep rooted legume crops, such as Lablab, runoff was reduced 22-72% (Nyawade, 2015). When runoff is decreased, nutrient use efficiency increases (Burke, 2016). Gitari (2005) observed that when Lablab was intercropped with potato it significantly increased potato nitrogen uptake efficiency in both the short and long rainy season in Nairobi, while nitrogen use efficiency was decreased when intercropping potato with shallower rooted green peas and common bean (Gitari, 2015). Many legume crops have also been shown to produce organic acids which solubilized plant unavailable phosphorous, increasing the uptake from the soil, and its use efficiency by associated plant (Zhang, 2003; Rao, 1999).

Potato Variety and Potato Intercropping Systems' effect on Water Use

As agriculture consumes a majority of the world fresh water, maximizing water use efficiency (WUE) while maintaining high yields in agricultural crops is crucial in the face of increasing water scarcity, especially in areas which already experience water scarcity and food insecurity (Sharma, 2015). WUE is the ratio of total biomass or grain yield to water supplied or evapotranspiration. In potato, the main factors which interact to determine WUE are genotype, amount of available nitrogen, soil moisture level, and soil type (Saravia, 2016). Crop spacing, and other management practices have also shown the ability to significantly influence WUE (Ritchie, 2008). In potato, both potassium and nitrogen soil nutrient status and can significantly affect WUE under less than optimal water availability, partially attributed to more rapid leaf area expansion allowing for higher transpiration and causing greater ground cover reducing evaporation (Badr, 2012; Ati, 2012; Li, 2004). Potato's shallow root system severely limits potential WUE and makes the plant highly susceptible to drought stress (Devaux, 2010).

Intercropping tends not to effect soil moisture status and evapotranspiration but can affect WUE (Sharaiha, 2013; Rezig 2014). In Sharaiha (2013) when intercropping potatoes with common bean, WUE significantly increased by 0.96 $kg/m^3$ and 0.83$kg/m^3$ which was attributed to a significant increase in yield of both crops when compared to monocropped treatments. Planting pattern also played a significant role in increasing yield and WUE (Jieming, 1990 ; Sharaiha, 2013). Rezig (2014) found intercropping bean and potatoes that WUE increased 24.4 to 35.8%. Similar results have been observed in a variety of intercropping studies such as those by Singh (2013) with a maize and legume intercropping system and One Acre Fund (2016) with a maize and potato intercropping system. Intercropping crops with root zones that occupy different levels of the soil can increase the total water and nutrient utilization and increase runoff infiltration (Burke, 2016). Intercropping crops with complementary above ground structures can provide more ground shade and reduce wind speeds in turn lowering soil water evaporation

(Burke, 2016). These attributes of intercropping are linked to increasing water use efficiency (Zhang, 2003; Amjad 2015; Burke, 2016) Cropping systems which reduce soil water evaporation and thus increase potential soil water content in turn enhances nutrient use efficiency thereby causing greater increase in yield and WUE (Ritchie, 1983, 2008).

Genotype also effects WUE in a variety of ways. Under water stress one critical trait linked to higher WUE is higher stomatal conductance to lower transpiration in times of lower soil water content (Obidiegwu, 2015). One issue with drought tolerant traits is they can often limit yield, such as stomatal closure conserving water but also reducing photosynthetic ability (Obidiegwu, 2015). When testing Unica in response to drought and fertilizer rates, Saravia (2016) found that WUE was highest under drought when recommended fertilization rates of 200kg N/ha were applied. Unica's relatively high WUE and yield when compared to other potato varieties has been attributed to its high N uptake in a variety of moisture condition and tolerance to drought stress (Saravia, 2016).

Potato Variety and Intercropping Systems' effect on Soil Microenvironment

Crop variety and systems have significant influence on temporal and spatial variability in soil physical and hydraulic properties. In a study integrating cereals, legumes and oilseeds in continuous and rotation systems, Liebig et al., (2004) recorded a significant increase in soil aggregate stability under rotational systems. The changes in total porosity are related to the changes in pore geometry depending on cropping system and soil type (Shahid, 2012). Water flow is mainly conducted by macropores (> 75 µm) and larger mesopores (30-75 µm) which are greatly influenced by different cropping systems and may decrease drastically under continuous monocultures (Moret and Arrúe, 2007; Mubarak et al., 2009). Intercropping and crop rotations decrease soil bulk density and increase the total porosity, increasing the amount of water held at high soil water potentials (Unger and Cassel, 1991; Lal et al., 1994). The response may however depend on soil texture. Unger (2012) showed that disrupting the natural structure decreased the water retention of coarse-textured soils and increased the retention of fine-textured soils relative to that of natural soil cores at a matric potential of -0.033 Mpa. Bhattacharyya et al., (2006) observed that water retention for soybean-wheat, soybean-lentil and soybean-field pea rotations was similar, indicating an absence of the effect of crop rotations on soil water retention. Bhattacharyya et al., (2008) also found higher plant available water holding capacity following 4 years of rice-wheat rotation. The higher infiltration rates under intercropping and crop rotation systems have been related to a greater number of macropores (Logsdon et al., 1990), increased fauna activity and the litter of residues formed by accumulated organic matter (Logsdon and Kaspar, 1995). Singh (2013) attributed the higher yield advantage of potato-peanut intercrop to nitrogen fixation and to the good canopy cover provided by the legume which controlled soil and nutrient losses due to erosion.

Crop varieties and systems also significantly effect soil temperature. Sharaiha (2013) reported that average soil and air heat units were significantly higher for sole potatoes than for potatoes intercropped with common beans in a two by two row intercrop pattern. Although bean light interception was higher when sole cropped, soil and air heat units were not significantly affected (Sharaiha, 2013). Managing soil temperature in potatoes is crucial as temperature inhibits the conversion of sucrose to starch within the tuber and thus affects potato production (Midmore, 1990). Most varieties of potato can have their yields sharply reduced when soil temperature rises above potato's ideal range of 14-22 °C. For example, when grown at a constant 27 °C, yields of the variety Desiree was 0% and Spunta was 15% of maximum yields (Hancock, 2013).

### Problem Statement

New potato varieties are being developed and released to build climate resilience but their performance in intercropping designs needs to be measured across different soil-climate gradients in Kenya to evaluate potential synergies between climate smart management options.

### Objective

To assess the performance of potato in potato/legume cropping system across different Kenyan agroecosystems and determine the relative contribution of and interactions between potato/legume cropping systems and a new climate smart potato variety to identify potential synergies between climate smart management options.

### Hypotheses

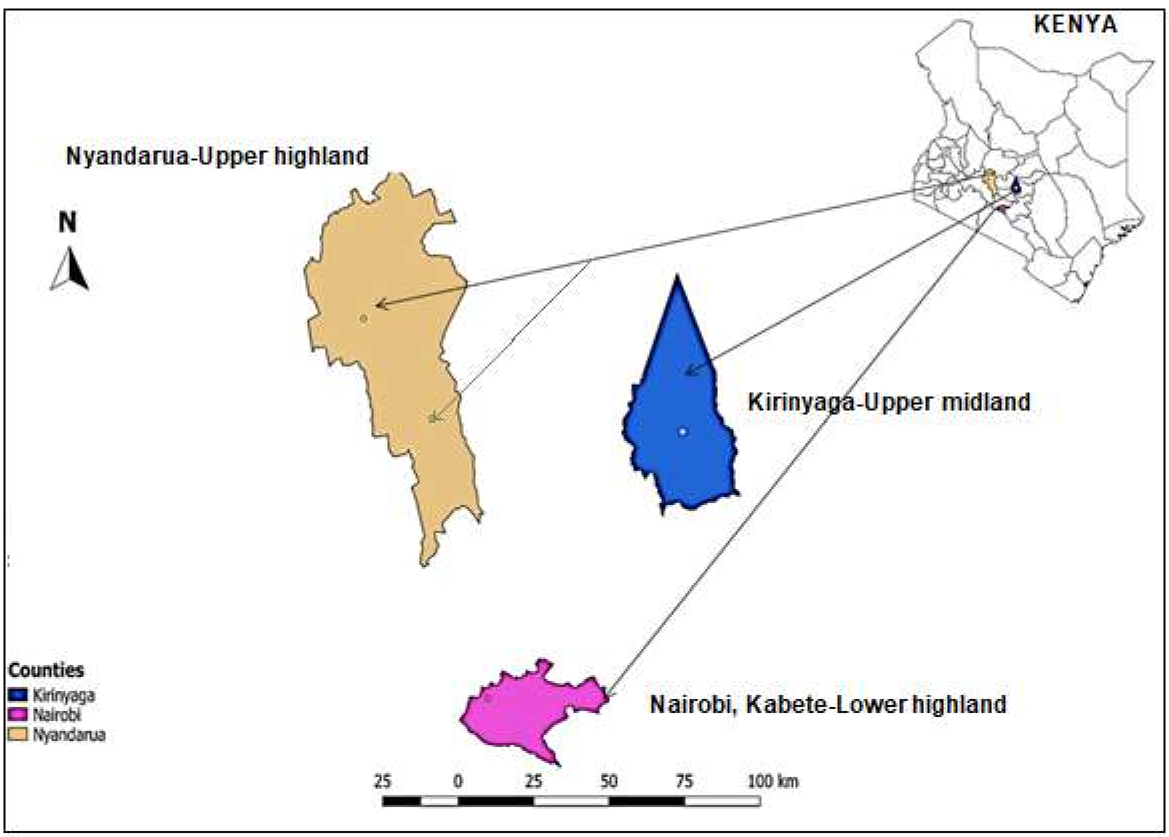
1. Potato variety will have a larger effect on yield, NPK use efficiency, and soil microenvironment across all sites than intercropping treatments.
2. Potato + Lablab intercropping treatment will have a positive interaction with the Unica potato variety increasing yield, NPK use efficiency, and soil microenvironment across all sites.

## MATERIALS AND METHODS

### **Experimental Site Description**

The experiment was conducted in Kenya in three farmer fields and one research station field at the University of Nairobi Upper Kabete Research Station in the long rainy season of 2017 (See Table 1 and Figure 1). Selection of sites was based on differences in agro-ecological zone, average rainfall data, temperature, altitude, soil type, and the potential for potato production. The goal was to achieve diverse sites that represented different agroecosystems where potato production occurs in Kenya. All on farm sites were managed by the farmers with instructions from the researchers. The research station sites were managed by the University of Nairobi field staff with instructions from the researchers. All site areas are densely populated with 150-500 inhabitants per km$^2$. Most farmers in areas surrounding each site grow maize intercropped with bean, sole potatoes, and grazing dairy cows on field edges on small land holdings.

**Figure 1: Experimental Site Map**



Experimental Design and Layout

The experiment trials were organized in a randomized complete split plot designs with 4 replicates per site. There were 4 blocks at each site with 3 main plots per block (one for each legume variety: lablab bean (*Lablab purpureous*) and lima bean (*Phaseolus lunatus*); and a sole potato *Unica and Sangi (Solanum tuberosum L*) with 3 subplots per main plot (an intercropping treatment for Unica and Shangi and sole legume treatment.) This creates 4 replications of each treatment combination per site. Each site was 44.1 x 26 m (~1146.6 $m^2$) with block boundaries of 1 m, mainplot boundaries of 1 m and boundaries between subplots of .5 m. The subplot size was 2.4 m x 5.25 m (12.6 $m^2$). Potatoes were planted as pre-sprouted tubers at 30 cm spacing within the rows and 90 cm distance between rows at a 10 cm depth. The lima bean and lablab were planted two seeds per hole at 24 cm spacing within the rows. The intercropping pattern was 2 rows potato to 2 rows legumes. This pattern is known as a 2:2 intercropping pattern or the "mbili system" in Kenya. (Mucheru-Muna et al., 2010)

**Table 1: Field Experimental Design Layout**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Block 1 | S+D | U+D | D | S+L | U+L | L | S | U |
| Block 2 | U | S | D | S+D | U+D | U+L | L | S+L |
| Block 3 | L | S+L | U+L | S | U | D | S+D | U+D |
| Block 4 | S+D | D | U+D | U+L | L | S+L | S | U |

*(S = Shangi, U = Unica, D = Dolichos, L = Lima, S+D = Shangi intercropped with Dolichos, and S = sole cropped Shangi. Colors indicate main plot groupings.)*

Trial Management

All trials were planted between April 17-30, 2017. Plants were fertilized only upon planting with legumes receiving triple superphosphate (TSP) 60 kg P $ha^{-1}$ while potato received NPK (17:17:17) at 100 kg N $ha^{-1}$, 100 kg P $ha^{-1}$ and 100 kg K $ha^{-1}$. Weed, pest and disease management were carried out throughout the study period using standard procedures for each specific area. The system was rainfed, as irrigation systems are uncommon for the area. Crop residues were incorporated into the soil at land preparation. All planting, land preparation, and management were done by hand and initial tillage was accomplished by animal driven plow. These are standard practices for the areas which were recommended by CIP. All seeds and tubers were from the CIP and the University of Nairobi and were of uniform quality and size.

Potatoes were harvested and weighed at maturity around 90 to 112 days after planting digging with forked hoes. Legumes were left growing in the field till they reach their respective maturities. Pods were to be harvested by hand all above ground biomass was to be harvested with machete weighed and then reincorporated into the soil, this step did not occur (see Discussion). These practices were selected to be representative of common practices used by Kenyan farmers. One main difference from common practice, however, was incorporating the above ground legume biomass into the soil, instead of removing it and using it for animal feed.

Soil Sampling and Analysis

Soil samples were collected using a soil auger from 0–15 cm and 15–30 cm depths. Each subplot was divided into 10 cells of which 5 were randomly selected for sampling. At each sampling point, surface organic litter was removed. The samples within a depth were deposited in a container and a sub-sample of about 1 kg transferred into sampling bags and transported to the laboratory for analyses of soil texture, pH, SOC, total N, available K and available P before planting. Soil moisture contents were determined gravimetrically at a temperature of 105°C while determinations of nitrate N content were done following the method of Keeney and Nelson (1982). Extraction of soil samples for analysis of available P and extractable K was done using Mehlich 1 procedures (Mylavarapu et al., 2002) and determined using UV–vis spectrophotometer

(Murphy and Riley, 1962) and flame photometry (Jackson, 1967) methods, respectively. Soil moisture content (%) was measured gravimetrically every two weeks through collecting 100g soil sample from each subplot and oven drying them. Soil moisture content was calculated by subtracting the soil wet weight (*g*) and soil dry weight (*g*) and then dividing that difference by the soil wet weight (*g).*

<u>Assessment of Yield and Resource Use</u>

Average subplot fresh yield, and dry matter yield was assessed at all sites as a function of area. Total fresh yield of each subplot except all boarder plants was measured in the field with a digital scale. Harvest occurred upon senescence and drying of potato foliage as per typical local farmer practice. The total above ground biomass of the legumes was harvested for animal feed. Fresh weight was to be measured at harvest in the field on a digital scale but did not occur (see Discussion). Dry shoot and tuber biomass were determined through a sample from central rows of each subplot at physiological maturity. A sample of 500 g of tubers/shoot was chopped into pieces, mixed and dried at 65°C for 48 hours in an air-forced oven for total dry matter weight (DM) determination and total nutrient uptake determination.

Nutrient uptake was measured by determining shoot and tuber nutrient concentration by sending the dried samples to the University of Nairobi's soil laboratory for analysis of the percent of nitrogen, phosphorous, and potassium for each sample.

Leaf area index (LAI), a ratio of leaf area cover to total ground area, was measured directly with a AccuPAR LP-80 Ceptometer. Measurements were taken on clear sky days between 11:30 and 1:30pm to minimize the effects of the angle of the sun. Readings were taken at an angle of 60 degrees to crop rows.

## Statistical Analyses

Statistical analysis was preformed using R software version 3.5.2 package. Tukey's Multiple Pairwise significance tests were completed using the Agricolae and lsmeans packages to separate the means at a $p \leq 0.05$ for each comparison between treatments within each agroecosystem. Variation between and within treatments was indicated by mean standard error of the means. ANOVA was used to indicate whether blocks, potato variety, intercropping system, or a potato variety:intercropping system interaction had a significant affect the parameters.

# RESULTS

## Site Agroecological Characteristics

Key site differences were elevation, soil type, mean temperature, and mean rainfall (see Table 2). All sites had soils with acidic pH (5 to 5.3), and similar levels of nitrogen and potassium. Key differences between soils were texture, hydraulic conductivity, and levels of phosphorus (see Table 3). During the 2016 short rains (September to March) the total rainfall amount was 366.2, 265.5, 312.2, and 416.4 mm for Tumaini, Kirinyaga, Kabete, and Kipipiri respectively. This experiment was conducted during the 2017 long rainy season (April to August) where the total rainfall amount was 582.67, 315.7, 605.3, 450.29 mm respectively. Kirinyaga was by far the hottest and driest site where plants were under constant water stress. Kirinyaga, Tumaini and Kipipiri all experienced and 2-week rain free period shortly after planting. Kabete and Kipipiri received an extended 3-week rain free period from the end of July into August (see Figure 2). Soil data was not collected from the Tumaini site and LAI was not collected form the Kirinyaga due to difficulties.

**Table 2: Site Characteristics**

| Site Region | Kiambu | Nyandarua-1 | Nyandarua-2 | Kirinyaga |
|---|---|---|---|---|
| Site Area Name | Kabete | Tumaini | Kipipiri | Kirinyaga |
| GPS location | 1° 15’ S 36° 44’ E | $0^{0}$15’48.11’’S $36^{0}$19’09.92’’E | $0^{0}$15’48.11’’S $36^{0}$19’09.92’’E | 1° 15’ S 36° 44’ E |
| Agro-ecological zone | Lower-Highland | Upper-Highland | Upper-Highland | Upper-Midland |
| Altitude (m) | 1940 | 2700 | 2500 | 1552 |
| Mean annual Rainfall (mm) | 800-1100 | 900-1500 | 900-1500 | 600-1000 |
| Mean Annual Max. Temp ($^{o}$C) | 15-26 | 10-23 | 10-23 | 18-29 |
| ET (mm) | 1152 | 1021 | 1021 | 1250 |
| Soil type | Humic Nitisols | Planosols | Ferric luvisol | Rhodic Ferralsol |
| Soil description | Dark reddish brown clay-loam soils with low to high SOM, an acid | Imperfectly to well drained, deep to very deep, dark brown to very dark grayish | Moderately to well drained, deep to very deep, dark brown to very dark red brown | Dark reddish brown, well drained, shallow to very deep, |

| | | | | |
|---|---|---|---|---|
| | top soil and high P sorption. | brown, moderate P sorption. | | |

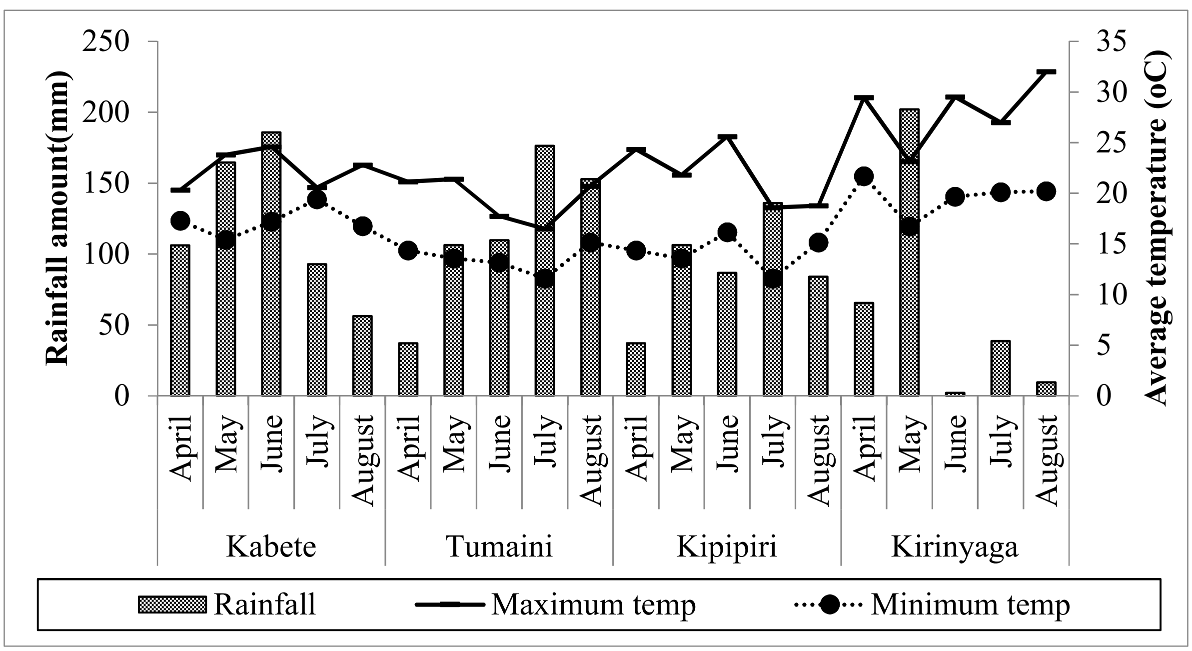
(Simbroek *et al.,* 2001; FAO, 2012; Jaetzold et al., 2006)

**Table 3: Measured soil properties of different soil layers before start of the experiment**

| | Soil depth | Clay | Silt | Sand | Texture | pb | θwp | θfc | θs | Ks | pH | som | N | P | K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | | % | | USDA | $gcm^{-3}$ | | $cm\ cm^{-3}$ | | mm $h^{-1}$ | | % | % | ppm | cmol/kg |
| Kirinyaga | 0-15 | 24.5 | 33.3 | 42.2 | Clay loam | 1.19 | 0.07 | 0.11 | 0.51 | 55.13 | 4.99 | 1.82 | 0.13 | 33.30 | 1.23 |
| | 15-30 | 24.2 | 36.9 | 38.9 | Clay loam | 1.24 | 0.04 | 0.09 | 0.52 | 49.21 | 4.99 | 1.04 | 0.23 | 23.40 | 1.33 |
| | 30-60 | 28.9 | 29.8 | 41.3 | Clay loam | 1.34 | 0.03 | 0.15 | 0.58 | 40.33 | 4.93 | 0.88 | 0.11 | 24.40 | 1.19 |
| | 60-90 | 23.8 | 32.4 | 43.8 | Clay loam | 1.35 | 0.03 | 0.18 | 0.55 | 32.22 | 4.92 | 0.33 | 0.09 | 20.20 | 1.09 |
| Kabete | 0-15 | 49.7 | 22.5 | 27.8 | Clay | 0.99 | 0.09 | 0.28 | 0.41 | 33.33 | 5.11 | 2.06 | 0.24 | 24.40 | 1.13 |
| | 15-30 | 49.2 | 24.2 | 28.9 | Clay | 1.04 | 0.06 | 0.27 | 0.41 | 27.56 | 5.14 | 1.56 | 0.11 | 18.20 | 1.16 |
| | 30-60 | 50.1 | 24.2 | 25.7 | Clay | 1.14 | 0.04 | 0.26 | 0.49 | 23.28 | 5.16 | 0.98 | 0.06 | 17.70 | 1.11 |
| | 60-90 | 51.3 | 24.8 | 23.9 | Clay | 1.19 | 0.05 | 0.28 | 0.48 | 14.98 | 5.20 | 0.42 | 0.02 | 16.60 | 1.00 |
| Kipipiri | 0-15 | 38.3 | 56.1 | 5.6 | Silty clay | 0.97 | 0.09 | 0.27 | 0.43 | 29.89 | 5.21 | 3.09 | 0.31 | 16.60 | 1.16 |
| | 15-30 | 36.9 | 58.4 | 4.7 | Silty clay | 1.00 | 0.08 | 0.29 | 0.42 | 26.87 | 5.22 | 2.34 | 0.23 | 17.90 | 1.15 |
| | 30-60 | 34.6 | 59.5 | 5.9 | Silty clay-loam | 1.08 | 0.03 | 0.25 | 0.45 | 18.32 | 5.26 | 1.92 | 0.11 | 15.50 | 1.03 |
| | 60-90 | 33.9 | 57.9 | 8.2 | Silty clay-loam | 1.11 | 0.04 | 0.26 | 0.41 | 9.04 | 5.28 | 0.98 | 0.09 | 14.90 | 1.02 |

*(pb is soil bulk density, ϑwp, ϑfc, ϑs indicate soil water content at permanent wilting point, field capacity and saturation respectively, Ks is saturated hydraulic conductivity. Samples taken at the being of the experiment)*

**Figure 2: Rainfall and Temperature monthly averages throughout experiment**



Overall Effects of Treatments and Interactions on Potato

Variety and cropping system had significant impacts on almost all parameters measured on a per plot basis at all sites, but there were no variety:cropping system interactions except in Kirinyaga (see Table 4). The variety:cropping system interaction observed in Kirinyaga is attributed to the Unica sole potato treatment having a significantly higher yield, NPK uptake, LAI, and soil moisture % below the canopy while all other treatments preformed equally low in these parameters. The significant effect of cropping system on Yield, NPK Uptake, and NPK % came from the difference between sole potato systems and the intercropping systems. Significant differences attributed to intercropping systems outside of the effect of potato variety were associated with LAI, and soil moisture %. LAI and soil moisture were highly correlated with one another.

**Table 4: Main effect on Yield, NPK% and NPK Uptake**

| Location | Cropping System | Fresh Yield (ton/ha) | N Uptake in Tuber (kg N/ha) | N% in Tuber (%) | K Uptake in Tuber ((kg K/ha) | Kppm in Tuber (ppm K) | P Uptake in Tuber ((kg K/ha) | Pppm in Tuber (%) | LAI | Soil Moisture % |
|---|---|---|---|---|---|---|---|---|---|---|
| Tumaini | Block | | | | | | | | | |
| | Variety | *** | *** | ** | *** | | ** | * | * | * |
| | Cropping System | *** | *** | ** | *** | | *** | *** | *** | *** |
| | VAR:CS | | | * | *** | | | | | |
| Kirinyaga | Block | | | | | | | | | |
| | Variety | *** | *** | *** | * | | *** | *** | ** | *** |
| | Cropping System | *** | *** | | * | | *** | | *** | * |
| | VAR:CS | *** | *** | | | | *** | | | |
| Kabete | Block | | | | | | | | | |
| | Variety | | | | *** | *** | | *** | * | |
| | Cropping System | *** | *** | | *** | | *** | | *** | ** |
| | VAR:CS | | | | | | | | | |
| Kipipiri | Block | | | | | | | | | |
| | Variety | | ** | * | | | * | ** | * | * |
| | Cropping System | *** | *** | | | | ** | | *** | ** |
| | VAR:CS | | | | | | | | | |

*(ANOVA of main effects. * = .05 level of significance, ** =.01 level of significance, ***=.001 level of significance)*

**Differences between Potato Varieties in Sole Potato treatments**

The new climate smart potato variety, Unica, had consistently higher vegetative growth, nutrient uptake, and yield when monocropped at all sites except Kabete, where it was equivalent in almost all measured variables with Shangi, the conventional variety (see Figure 3 and Table 5). One significant difference was that Unica had a consistently higher LAI starting after Week 3 or 5 depending on the site (Figure 4). % NPK Tuber uptake was also almost always higher in Unica than Shangi but it was not significant in most cases due to high variance and small difference.

Differences between Intercropping Systems

There were minimal significant differences between intercropping treatments within the same potato variety on yield, NPK uptake, and NPK %. LAI index and soil moisture % were significantly affected by intercropping treatment but the effect changed depending on site. At the Kabete site the Potato + Lablab treatment showed significantly higher LAI and soil moisture % between week 5 and harvest when compared to Potato + Lima. While at Tumaini and Kipipiri, Potato + Lima showed significantly higher LAI and soil moisture % between week 5 and harvest when compared to Potato + Lablab (Figure 4 and 5).

**Figure 3: Average Potato Yield:**

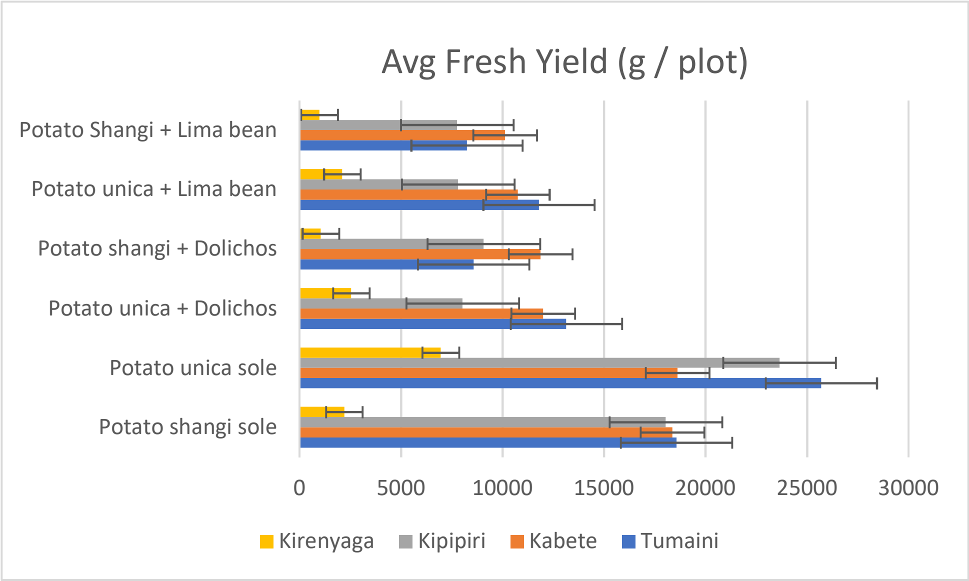


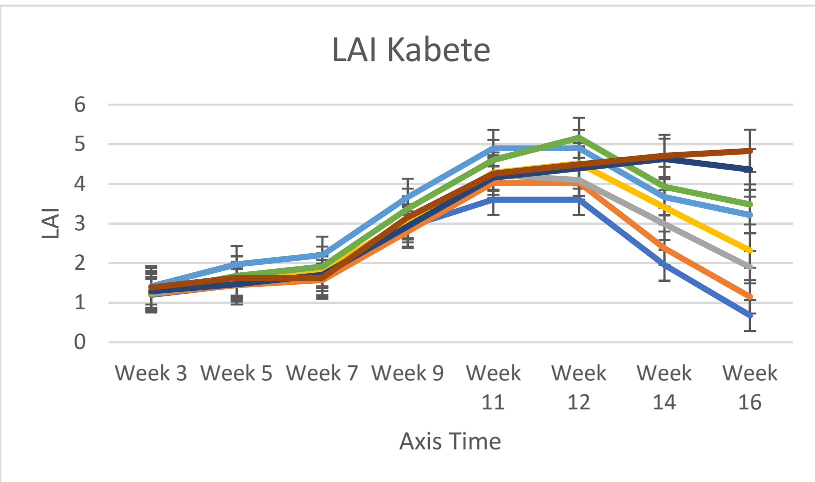

**Table 5: Effect of Cropping System and Variety on Average Yield, NPK % and NPK Uptake**

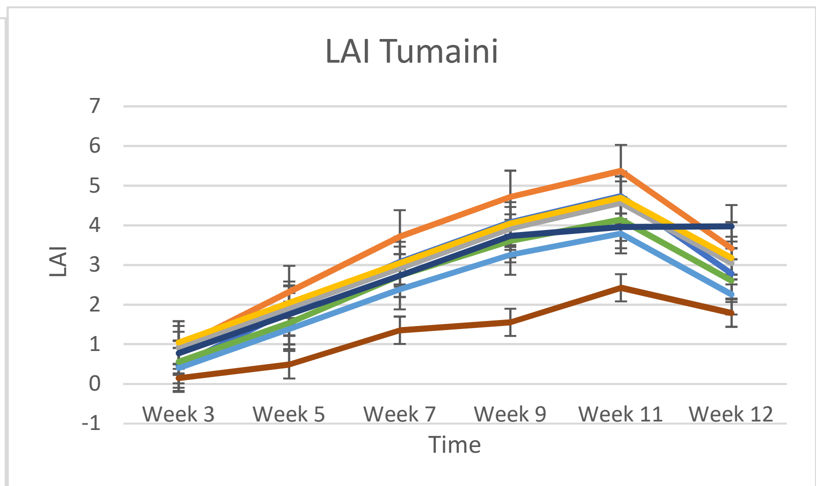
| Location | Cropping System | Fresh Yield (ton/ha) | N Uptake in Tuber (kg N/ha) | N% in Tuber (%) | K Uptake in Tuber (kg K/ha) | K ppm in Tuber (ppm K) | P Uptake in Tuber ((kg K/ha) | P ppm in Tube (ppm P) |
|---|---|---|---|---|---|---|---|---|
| Tumaini | Unica + Lima | 8.62ab | 80.57ab | 4.24ab | 11.80b | 11833ab | 89.8ab | 4738c |
| | Shangi + Lima | 6.02a | 49.28a | 3.88ab | 4.52a | 10375ab | 59.9a | 4728c |
| | Unica + Lablab | 9.61ab | 77.11ab | 3.63a | 14.04b | 10666ab | 91.4ab | 4233ab |
| | Shangi + Lablab | 6.27a | 46.63a | 3.63a | 3.97a | 8208a | 53.0a | 4092a |
| | Unica Sole | 18.79c | 172.35c | 4.45b | 35.48c | 10417b | 178.3c | 4621bc |
| | Shangi Sole | 13.57b | 119.04b | 3.67a | 8.45ab | 9208a | 135bc | 4221ab |
| | *Std error of mean* | 1.08 | 7.67 | .106 | 1.53 | 541 | 12.6 | 95.7 |
| Kirinyaga | Unica + Lima | 1.54ab | 11.30ab | 3.38b | 42.45ab | 8333ab | 6.91ab | 2123ab |
| | Shangi + Lima | .717a | 3.90a | 2.66ab | 30.59a | 6291a | 2.87a | 1827a |
| | Unica + Lablab | 1.86b | 14.30b | 3.20ab | 60.19ab | 9750b | 11.11b | 2494b |
| | Shangi + Lablab | .77a | 4.48a | 2.57a | 48.10ab | 6875a | 3.03a | 1925ab |
| | Unica Sole | 5.08c | 34.99c | 2.99ab | 92.4b | 9667b | 26.25c | 2246ab |
| | Shangi Sole | 1.61ab | 8.3ab | 2.48a | 53.7ab | 6792a | 5.88a | 1846a |
| | *Std error of mean* | .217 | 1.34 | .157 | 11.5 | 685 | 1.13 | 125 |
| Kabete | Unica + Lima | 7.85a | 53.44a | 3.15a | 66.49abc | 10500ab | 69.6a | 4123ab |
| | Shangi + Lima | 7.40a | 55.49a | 3.44a | 35.34a | 8458.33a | 63.7a | 3827a |
| | Unica + Lablab | 8.77a | 63.85ab | 3.21a | 81.86bc | 11542ab | 88.3abc | 4494b |
| | Shangi + Lablab | 8.68a | 56.72a | 2.86a | 39.43ab | 9041ab | 79.2ab | 3925ab |
| | Unica Sole | 13.61b | 104.66c | 3.48a | 95.2c | 11125b | 128.1c | 4246ab |
| | Shangi Sole | 13.43b | 89.16bc | 2.99a | 142.9d | 8875ab | 114.9bc | 3846a |
| | *Std error of mean* | 1.07 | 7.67 | .176 | 9.31 | 649 | 8.9 | 125 |
| Kipipiri | Unica + Lima | 5.71ab | 40.15a | 3.03a | 90.60a | 10416.66a | 51.0a | 3833a |

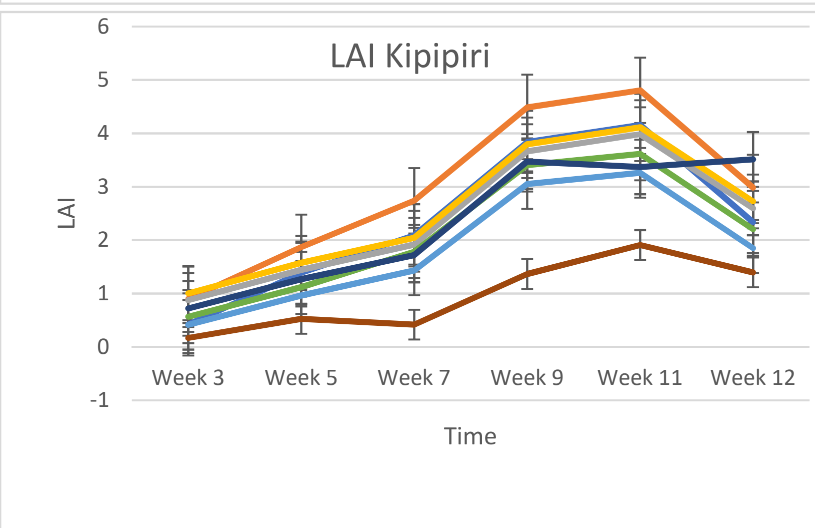
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Shangi + Lima | 5.67a | 24.98a | 2.50a | 79.50a | 9916.66a | 37.1a | 3671a |
| Unica + Lablab | 5.87ab | 38.32a | 3.22a | 61.49a | 8916.66a | 49.8a | 4167a |
| Shangi + Lablab | 6.63ab | 31.67a | 2.65a | 55.83a | 7916.66a | 40.0a | 3362a |
| Unica Sole | 17.28c | 107.76b | 3.12a | 65.6a | 10583a | 93.6b | 3888a |
| Shangi Sole | 13.19bc | 63.14a | 2.63a | 15.5a | 8667a | 41.08ab | 3458a |
| *Std error of mean* | 1.24 | 6.35 | .229 | 17 | 559 | 9.96 | 144 |

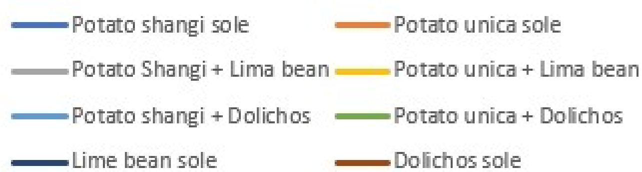
*(Means followed by the same letter within a column within an area indicate lack of significant differences by Tukey's LSD test ($p \leq 0.05$).*

**Figure 4: LAI Throughout Growing Season**



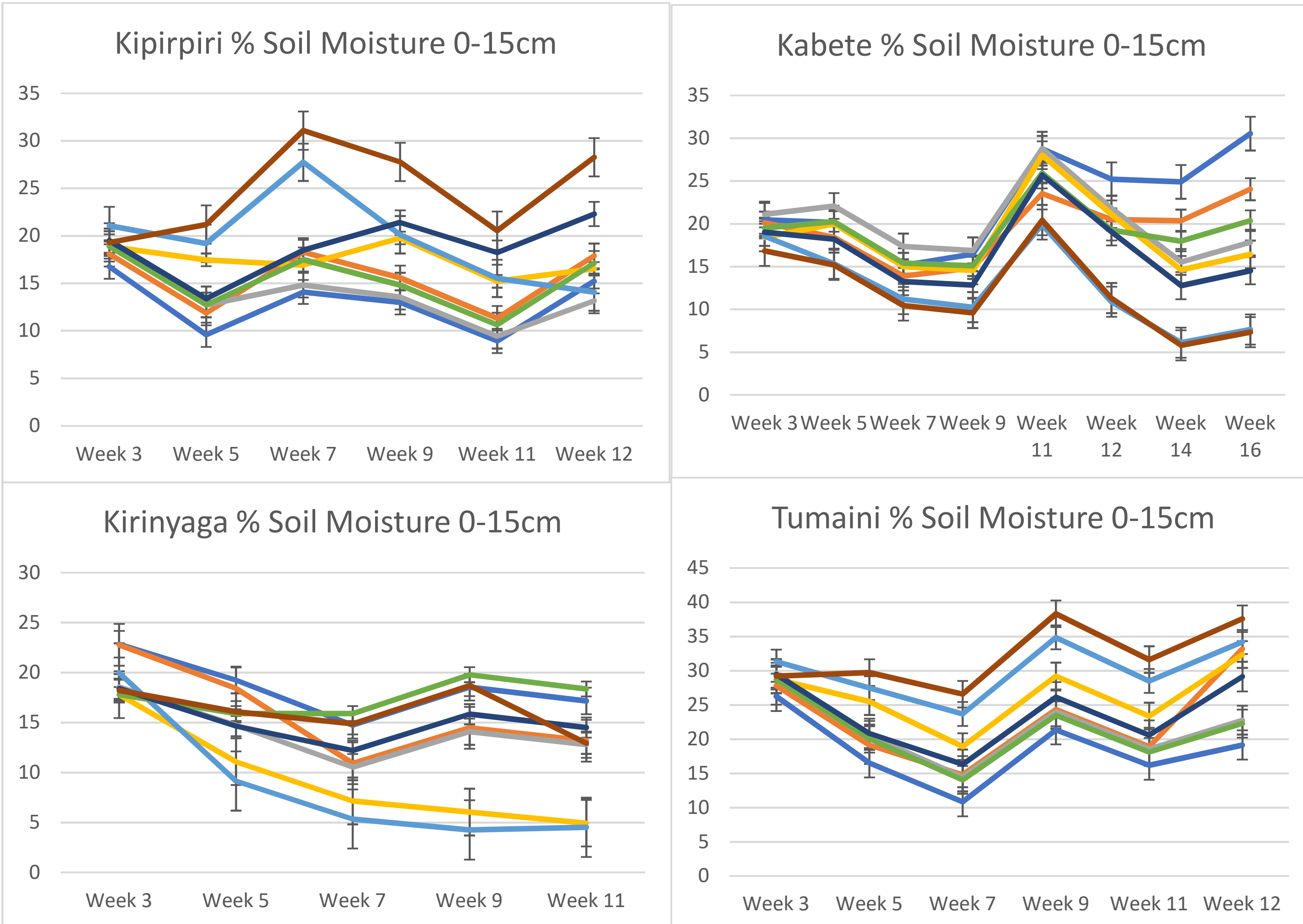



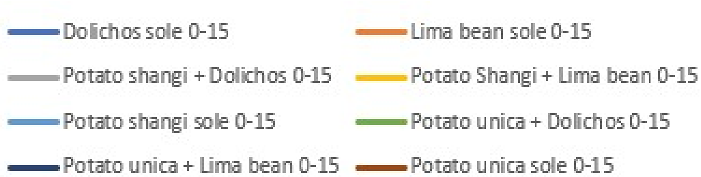




*(All graphs use same colors to indicate treatment.)*

**Figure 5: % Soil Moisture Throughout Growing Season**




*(All graphs use same colors to indicate treatment.)*

<u>Differences between Sole Potato and Potato Intercropping Systems</u>

The significance of the effects of potato variety and cropping system on yield, and NPK uptake varied significantly depending on the site (Table 6). Given the high variance in many parameters, it was not possible to find significant differences between treatments. Unica's yield and NPK uptake per plant was consistently higher than respective Shangi treatments at all sites. The Potato + Lablab cropping system had a consistently higher yield and NPK uptake per plant at all sites when compared to the Potato + Lima cropping system of its respective potato variety. The sole potato cropping system had consistently higher yield and NPK uptake per plant than both intercropping treatments at all sites except at Kabete where yield and NPK uptake were significantly higher in the Potato + Lablab treatment. Many of these observed trends were not significant at an alpha level of .05 except for the Kirinyaga site due to the lower variance within treatments (Table 7 and Figure 6).

**Table 6: Main effect on Yield, NPK% and NPK Uptake**

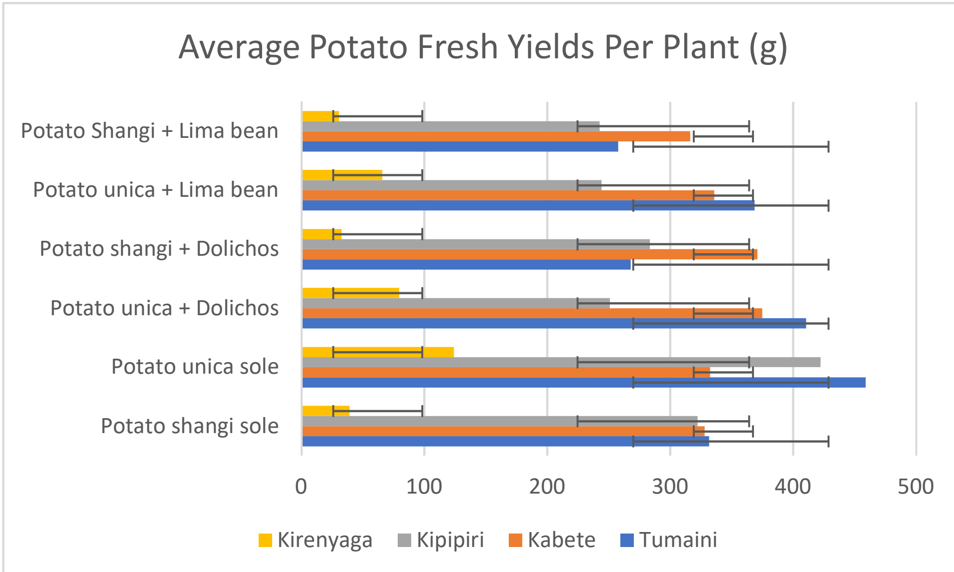
| Location | Cropping System | Fresh Yield (g/plant) | N Uptake in Tuber (kg N/plant) | K Uptake in Tuber ((kg K/plant) | P Uptake in Tuber ((kg K/plant) |
|---|---|---|---|---|---|
| Tumaini | Block | | | | |
| | Variety | *** | *** | *** | ** |
| | Cropping System | | * | * | |
| | VAR:CS | | | * | |
| Kirinyaga | Block | | | | |
| | Variety | *** | *** | | *** |
| | Cropping System | ** | ** | | *** |
| | VAR:CS | * | * | | ** |
| Kabete | Block | | | | |
| | Variety | | | *** | |
| | Cropping System | | | | |
| | VAR:CS | | | | |
| Kipipiri | Block | | | | |
| | Variety | | * | | * |
| | Cropping System | * | * | * | |
| | VAR:CS | | | | |

*(* = .05 level of significance, ** =.01 level of significance, ***=.001 level of significance)*

**Table 7: Effect of Cropping System and Variety on Average Yield, NPK % and NPK Uptake per plant**

| Location | Cropping System | Fresh Yield (g/plant) | N Uptake in Tuber (g N/plant) | K Uptake in Tuber (g K/plant) | P Uptake in Tuber ((g K/plant) |
|---|---|---|---|---|---|
| Tumaini | Unica + Lima | 369ab | 3444ab | 504b | 3838ab |
| | Shangi + Lima | 258a | 2107a | 193a | 2561ab |
| | Unica + Lablab | 411ab | 3296ab | 600b | 3907ab |
| | Shangi + Lablab | 268a | 1993a | 170a | 2264a |
| | Unica Sole | 459b | 4210b | 867c | 4356b |
| | Shangi Sole | 332ab | 2908ab | 206a | 3319ab |
| | *Std error of mean* | 36.8 | 357 | 56.3 | 437 |
| Kirinyaga | Unica + Lima | 65.8ab | 483b | 1815a | 295b |
| | Shangi + Lima | 30.7a | 167a | 1308a | 123a |
| | Unica + Lablab | 79.7b | 611bc | 2573a | 475c |
| | Shangi + Lablab | 32.8.a | 191a | 2056a | 130ab |
| | Unica Sole | 124.2c | 855c | 2258a | 641c |
| | Shangi Sole | 39.3a | 203a | 2573a | 144ab |
| | *Std error of mean* | 7.82 | 56.4 | 398 | 36.9 |
| Kabete | Unica + Lima | 336a | 2285a | 2842ab | 2976a |
| | Shangi + Lima | 316a | 2372a | 1511a | 2724a |
| | Unica + Lablab | 375a | 2729a | 3500b | 3776a |
| | Shangi + Lablab | 371a | 2425a | 1686a | 3385a |
| | Unica Sole | 333a | 2557a | 3490b | 3129a |
| | Shangi Sole | 328a | 2178a | 2326ab | 2807a |
| | *Std error of mean* | 53.9 | 273 | 305 | 336 |
| | Unica + Lima | 244a | 1716ab | 3873b | 2181ab |
| Kipipiri | Shangi + Lima | 243a | 1068a | 3399ab | 1585a |
| | Unica + Lablab | 251a | 1638ab | 2629ab | 2129ab |
| | Shangi + Lablab | 284a | 1354ab | 2387ab | 1708ab |
| | Unica Sole | 422a | 2632b | 1603ab | 3312b |
| | Shangi Sole | 322a | 1543ab | 378a | 2030ab |
| | *Std error of mean* | 37 | 217 | 368 | 280 |

**Figure 6: Average Potato Yield per Plant**




<u>DISCUSSION</u>

Two key factors during this experiment greatly influenced its outcomes and conclusions. The first was a lack of rainfall at all sites except Kabete early in the season which put the legumes through severe water stress shortly after emergence and dramatically inhibited their growth and ability to bounce back. The LAI of sole dolichos only reached 2 by the end of the season at both Kienyaga and Kipipiri, while at Kabete the LAI reached 5 by the end of the season (see Figure 4). These low values greatly influenced the ability of the legumes to provide shade for the potatoes and decrease soil temperature which is a significant factor contributing to yield, soil moisture and resource use efficiency gains observed in potato intercropping systems (Sharaiha, 2013; Midmore, 1990). Soil moisture variation also differed dramatically between Kabete and the other three sites. Soil moisture % was highest in the sole potato treatments for most of the experiement at all sites except Kabete where sole potato treatments had the lowest soil moisture % throughout the experiment compared to all other treatments (see Figure 5).

The other key factor influencing this experiment's conclusions was the failure collect several important data points. The largest failure of data collection came from the inability to harvest the legumes to get their biomass and nutritional data due to travel being restricted for several weeks due to widespread protests of the Kenyan election occurring during the harvest period for the legumes. With legume data, calculating the LER (Wiley, 1979; Burke 2017) would have been possible and better analysis could have been done in comparing sole and intercropped treatments. Instead per plant potato yield was estimated which lowered statistical power to assess differences between treatments. The second failure of data collection came from the inability to collect soil temperature data due to insufficient soil temperature/moisture data loggers. Soil temperature has a large affect on potato yield and is influenced by LAI and soil moisture (Sharaiha, 2013; Midmore, 1990). With soil temperature data the relationship between these variables could have been much more meaningfully described. If this experiment is redone or similar experiments are created, soil temperature data, irrigation, and legume data must be included.

Although sole potato treatments achieved the highest productivity based on most of the parameters measured during this experiment, there was evidence, albeit not significant, of the Lablab + Potato intercropping treatment at Kabete being more productive on almost all measured parameters on a per plant basis. However, there was no difference between any of the respective Unica and Shangi treatments at Kabete even when artificially raising the statistical power which gives some evidence there is no additive affect between either these two potato varieties and the intercropping treatments. As mentioned earlier, Kabete was the only site where legumes grew to their expected potential. The fact that the Potato + Lablab treatments had a higher yield and NPK uptake at Kabete compared to other respective intercropped and monocropped treatments was not a surprise as it was also observed at the same site by Gitari (2015) using the Shangi variety. Unica has been observed to have higher yields than many conventional varieties in Kenya (Schulte-Geldermann, 2013; Saravia, 2016).

It is also important to note that both the Lablab and Lima varieties were selected because they are some of the most drought and heat stress tolerant legumes commonly grown in Kenya. The fact that potatoes were more resistant to early season drought than these legumes casts doubt on the potential for potato/legume intercropping systems as a strategy to increase smallholder Kenyan farmers' resilience to climate change. In Kenya a vast majority of smallholder farmers rely solely on rainfall for irrigation. With increasing temperature and variability of precipitation predicted and observed in much of Kenya the chance of early season drought will likely increase into the future (Ngigi 2009; Lasco et al. 2014). Corn/legume intercropping systems might be a more optimal intercropping system when considering the potential of early season drought (One Acre Fund, 2016). Another key consideration is that livestock are commonly grazed on field edges in Kenya in potato growing regions. At 3 of 4 sites livestock did some level of damage to legume plants but did not touch the potato plants. Considering the risk of livestock damage to legumes, fencing of the research plots is likely to be required. This also contributes negatively to the viability of potato legume intercropping systems.

## CONCLUSION

Although sole cropping systems outperformed intercropping treatments for almost all measured parameters during this experiment, there is still strong evidence that potato/legume intercropping systems have potential to assist in increasing the productivity and resilience of

Kenya's potato industry. CIP is continuing to explore the effects and viability of potato/legume intercropping systems. New climate-smart varieties like Unica show a great potential to increase yields and resilience throughout Kenya and pairing Unica with clean seed technologies and fertilizer will hopefully allow for its quick and successful adoption.

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