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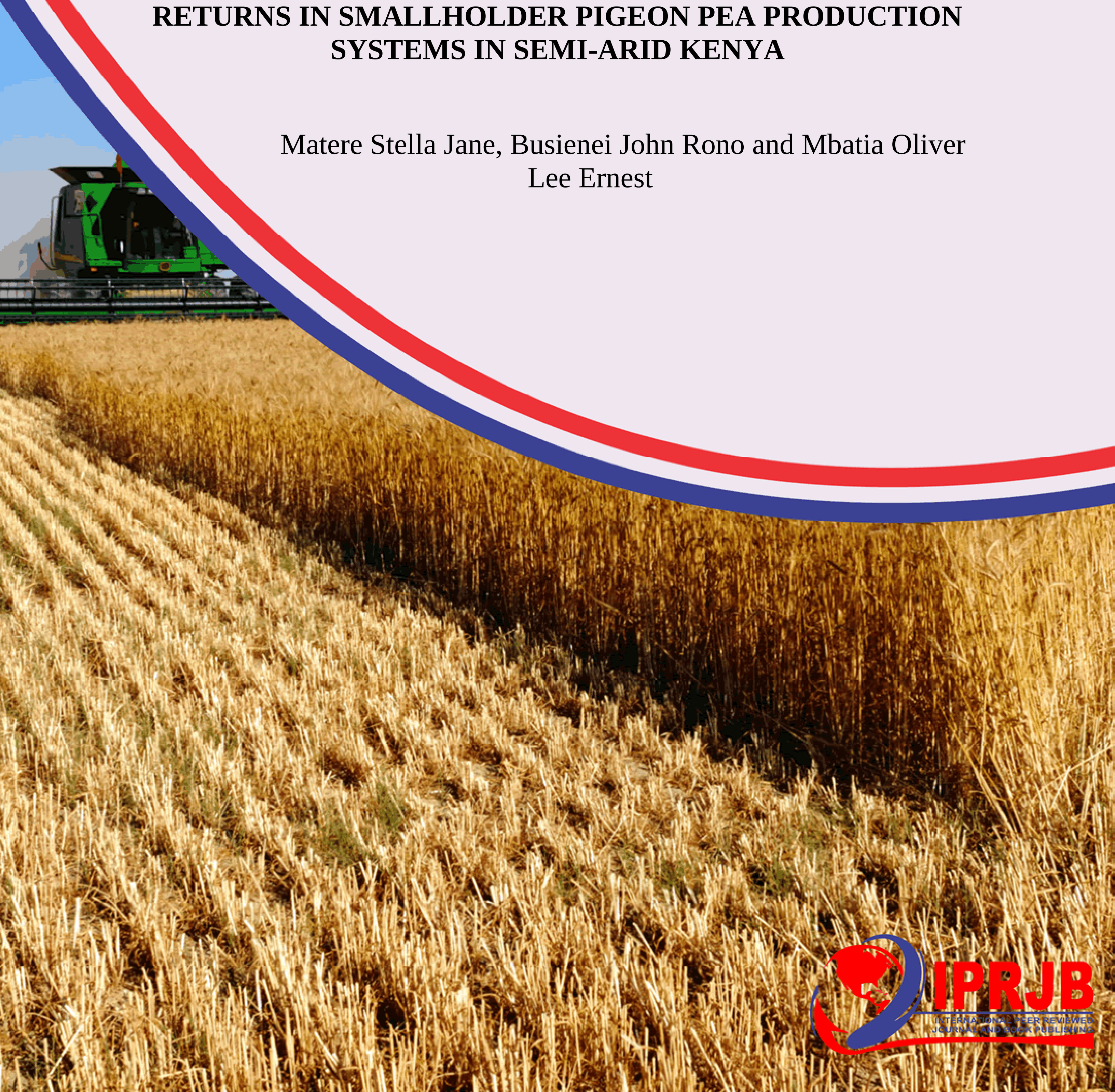

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IMPACT OF ADAPTATION TO CLIMATE CHANGE ON NET RETURNS IN SMALLHOLDER PIGEON PEA PRODUCTION SYSTEMS IN SEMI-ARID KENYA

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Abstract

Purpose: Improved pigeon pea varieties were promoted in semi-arid areas of Kenya to improve smallholder pigeon production systems resilience to climate change. However, the impact of adoption is unknown. This study was carried out to evaluate the impact of adoption on farming households' net farm returns in semi-arid South Eastern Kenya in the context of adaptation to climate change. The objectives were to (i)describe farmer's perceptions on production of improved varieties of pigeon peas as an adaptation strategy to climate change, (ii) evaluate the impact of the adoption on household's net returns. Propensity score matching approach was used to assess the impact of the adoption.

Methodology: The study used cross sectional data gathered through household survey to evaluate the impact of adoption on farming households' net farm returns in semi-arid South Eastern Kenya in the context of adaptation to climate change.. The study was conducted in semi-arid zones of Machakos County in South Eastern Kenya (SEK) namely Masinga, Mavoko and Mwala Wards. The areas were purposively selected for semi-arid semi-arid climatic conditions and dominant pigeon pea production.The study adopts the counterfactual approach and propensity score matching method to evaluate the impact of adopting improved pigeon peas on household net farm income. Data was analyzed using STATA 13.0 statistical package.

Findings: The results showed that 33 percent of the sampled households had adopted production of improved pigeon peas and they perceived adoption of the technology as an adaptation strategy to climate change viewed through tolerance to drought, pest and diseases, increased crop yield and shortened crop growth period. Improved pigeon peas significantly increased farmers' net income, the adopter got a net farm income of KES 30,710 per acre per year that was KES 18, 631 more than non-adopting households.

Unique contribution to theory, practice and policy: The study recommends that County Governments facilitate farmers to produce pigeon pea seeds through improved access to seed and linkage to reliable market for their farm produce to increase their farm income.

Keywords: climate change, Adoption, Pigeon pea, Income Propensity score matching, Semi-arid areas Kenya.

1.0 INTRODUCTION

Pigeonpea (*Cajanus Cajan* L. Millsp.) is the third most important grain legume worldwide (FAOSTAT, 2019). It is cultivated on about 7.02 million hectares with an annual production of 6.8 million metric tons and productivity of 0.97 tons per hectare (FAOSTAT, 2019). In Africa, it is grown in more than 33 countries with Malawi leading in production (434,792t), Tanzania (315,837t), Kenya (85, 684t) and Uganda (11,047t) per year. Kenya is ranked the fifth (2.1%) after India 62.7%, Myanmar (21.3%), Malawi (6%) and Tanzania (4.9%).

Pigeon pea is predominantly produced in smallholder farming systems in semi-arid areas in Kenya favoured for its adaptability to dry weather conditions as it produces some yields during the dry spells when other grain legumes and cereals wilt and dry up as a result of heat and moisture stress. To enhance smallholders' pigeon pea production system's resilience to climate change, and increase farm income, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) collaborated with Kenya Agricultural Research Institute (KARI) currently the Kenya Agricultural and Livestock Research Organization (KALRO) and the University of Nairobi in development of several improved pigeon pea varieties (Olubayo *et al.*, 2002). The first early maturing varieties released in Eastern Africa included ICPL 87091 and Kat60/8 (Silim *et al.*, 2001). The medium maturing pigeon pea varieties were ICEAP 00554 and 00557 both for grain as well as green vegetable purposes. The varieties have high-yielding, early-maturing, drought-tolerance and *Fusarium* wilt disease resistance traits and preferred on the market. To bolster production, the dryland seed program was set up to stimulate adoption of dryland adapted crops. Seed crops were grown under the guidance of seed specialists and plant breeders from the collaborating institutions. Farms with suitable land, managerial and other resources were contracted for seed multiplication. Some identified farmers were given small amounts of seed on loan to bulk on terms of repaying the seed in kind and keep the remainder. The repaid seed was "lent on" to other farmers to expand the bulking of seed. Kwena *et al.*, (2018) reports that improved pigeon pea have potential to yield of 3 tons per ha per year relative to the indigenous that yield just a third portraying its suitability for enhancing smallholder farming resilience to the shocks of climate change. As droughts become common and dry lands expand due to climate change, pigeon pea remains an important crop for food and nutritional security and a source of income in semi-arid Kenya (Cheboi *et al*., 2016; Gok, 2016; Kwena *et al.*, 2018). The peas are protein rich which are crucial for nutrition security especially because about 55% of the rural population in SEK are poor and unlikely to afford sufficient animal proteins (GoK, 2015). Information on impact of pigeon pea production on farmers is therefore important for rural agricultural adaptation planning.

Climate change has deleterious impact on agricultural production. The Intergovernmental Panel on Climate Change (IPCC) indicates that an increase in global temperature will affect agricultural productivity, particularly in the tropics whose impact will rise with increase in temperature (IPCC, 2014). In general, high temperatures and changes in rainfall patterns are likely to reduce crop productivity, increase pressures from pests and diseases (Niang *et al.*, 2014). Sub-Saharan Africa (SSA) will be the most vulnerable to climate change globally due to high dependence on agriculture, multiple stresses of poverty, poor infrastructure and governance (Shackleton *et al.*, 2015). Agricultural productivity in the region will be further undermined by degradation of agricultural land available and expansion of crop production into low potential land. The semi-arid areas will be affected because of the fragile nature of the resources they have access to (IPCC, 2007; 2014) while the highly variable rainfall would make rain-fed agriculture more precarious (Niang *et al*., 2014).

Kenya's landmass is 80% arid and semi-arid areas (ASALs) which are prone to extremes of drought and floods despite their low levels of rainfall of 300–500 mm annually (Gichangi *et al.*, 2015; Herero *et al.*, 2010). The impacts of droughts on the farming communities are increasing due to high population growth and encroachment of agricultural activities in such areas, changing them from rangeland to mixed systems. The IPCC (2007; 2014) and the Food and Agriculture Organization of the United Nations (FAO) underscores the need of African agriculture to adapt to climate change to reduce the adverse effects of climate change. The Government of Kenya takes cognizance of importance of adaptation to minimize the negative impacts of climate change in semi-arid areas. The Kenya National Adaptation plan of 2015-2030 recognizes growing of drought tolerant crops as adaptation to climate change in semi-arid areas of the country (GoK, 2016).

Tropical legumes have been suggested to contribute to improved food security and household welfare in smallholder farming systems in SSA (Amare *et al.*, 2012; Gwata, 2010; Wambua *et al.*, 2017). Pigeon pea (*Cajanus Cajan* L. Millsp) is one of the major staple crops grown in semi-arid areas of Kenya, it accounts for 67% of the total production in the country (Kimiti *et al.*, 2009; Wambua *et al.*, 2017). Pigeon pea is a genetically diverse crop with several varieties that differ in time to maturity. A number of these varieties are perennial in nature, with a shrubby habit that helps them last several growing seasons and regrow after harvest (Saxena *et al*., 2010). The main products of the crop are dry grain and green pods produced for both subsistence and commercial purposes. The seeds are highly nutritious, mature seeds contain 18.8% protein, 53% starch, 2.3% fat, 6.6% crude fiber and rich in minerals (Saxena *et al*., 2010). Pigeon pea biomass is used as livestock fodder while the stems are used as fuel wood in resource-poor households. The roots of the crop fix nitrogen into the soil and release soil-bound phosphorus, thus ameliorating the nitrogen and phosphorus deficiencies that typify most soils in the dry areas in Kenya (Kwena *et al.*, 2019; Odeny, 2007). The crop's tolerance to both biotic and abiotic stress makes it adaptable to semi-arid areas that are perennially water stressed (Kwena *et al.*, 2018). The growing demand for the crop in both local and export market provides a source of food and income to the majority smallholder producers (Makelo *et al*., 2013). The production of improved pigeon peas is expected to strengthen smallholder farming systems in semi-arid areas adaptation to climate change and positively impact on farmers' welfare. However, the empirical evidence on the adoption and performance of pigeon pea production technologies is scanty and therefore the impact is largely unknown.

2.0 LITERATURE REVIEW

2.1 Theoretical framework

This study adopts the utility theory which is concerned with people's choices and decisions. The theory is pegged on the premise that any decision is made on the basis of the utility maximization principle according to which, best choice is the one that provides the highest utility (satisfaction) to the decision maker. In this case, the farmer in semi-arid areas of Machakos County is a consumer of an agricultural technology and the farmer/decision maker has to have positive perception of the technology and decides to grow improved varieties of pigeon peas to secure the highest possible level of total utility through increased yield and farm income. The utility derived from adopting or not is measured by a utility function U, which is a representation of the farmer's decision making system of preferences.

Let U_{i1} and U_{i0} represent a farming household utility derived from two choices. The assumption is that a household gets expected utility from the choice made. Farmer *i* adopts improved pigeon peas if the expected utility of adoption U_{i1} is greater than U_{i0} (the expected utility of not adopting) subject to some variables such as years of farming experience, level of education, income, access to information among others. If $U_{i1} > U_{i0}$, then:

$U_i = U_{i1} - U_{i0} > 0(1)$………………………………………………………………(1)

Based on the theory of utility maximization, a rational firm will adopt the technology when the utility derived from adoption is greater than that from non-adoption. However, utility is unobservable. A binary random variable Y_i that takes the value of 1 if the technology is adopted and 0 (zero) otherwise can be observed.

Mathematically the utility function can be expressed as: $U_{i1} = g'\beta_{i1} + h'_{i1}\gamma_{i1} + \varepsilon_{i1}$ for adopters and $U_{i0} = g'\beta_{i0} + h'_{i0}\gamma_{i0} + \varepsilon_{i0}$ for non-adopters. The observable vector of households characteristics are denoted by g' while h' denote a vector of any choice-specific attributes, ε_{i1} andε_{i0} are the stochastic elements that are not known by the observer. In the case of $Y_i = 1$, it is concluded that $U_{i1} > U_{i0}$.The utility function can be expressed as:

$U_i = g'(\beta_{i1} - \beta_{i0}) + h'_i(\gamma_{i1} - \gamma_{i0}) + \varepsilon_{i1} - \varepsilon_{i0} = g'\beta_i + h'_i\gamma_{i1} + \varepsilon_i$. $\varepsilon_{i1}, \varepsilon_{i0}, \varepsilon_i$ are error terms, and adopting the binary logit model the probabilities of choice of growing improved pigeon peas can be estimated as:

$Z_i = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \varepsilon_i$………………………………………………………….. (2)

Where $\beta_i$represents estimated parameters and *X* represents factors influencing adoption of improved pigeon peas such as gender, education, years of farming experience of the household head, and other socio-economic and institutional variables and $\varepsilon_i$represents error term.

A large body of empirical literature has documented that adopting agricultural technologies increases productivity and farm income household incomes. Amare et al.,(2012) examined farmers' decisions to adopt improved pigeon pea and maize and estimated the causal impact of technology adoption on smallholders household welfare in Tanzania. The authors used both propensity score matching and switching regression techniques. The authors identified inadequate local supply of seed, access to information, human capital, and access to private productive asset as key constraints for pigeon pea technology adoption. The causal impact estimation showed that maize/pigeon pea adoption had a positive and significant impact on income and consumption expenditure among sample households. Mishra et al., (2018) examined the impact of the adoption of contract farming on yields, profitability and costs of smallholder lentil farms in Nepal. Using the propensity score matching they found that the technology only had positive impact on very smallholder lentil farms with 0.01-0.05 hectares who experienced a positive and significant effect on per-hectare revenues, profits and yield and a negative impact on transportation costs. Tesefaye *et al.,* (2016) assessed the impact of adopting improved wheat varieties and inorganic fertilizers on farmers' income in Aris zone Ethiopia. The propensity score matching approach was applied in estimating the rate of adoption and the impact of adoption on farm households' income. The rate of adoption was 56percent in the year 2013. Adopters got increased production by 1.1 tons per hectare compared to the non-adopters and had an increase of farm income by a range of 35 to 50percent. Wu *et al*., (2010) conducted an impact study in rural China and found that adoption of agricultural technologies had a positive impact on farmers' wellbeing thereby improving household incomes. Becerril and Abdulai (2010) also used PSM to analyze the impact of adopting improved maize varieties on household incomes and poverty reduction using cross-sectional data for 325 farmers in Mexico. Their findings show a robust, positive and significant impact of improved maize variety adoption on farm household welfare measured by per capita expenditure and poverty reduction. The adoption of improved maize varieties helped in raising household per capita expenditure by an average of 136–173 Mexican pesos. Mendola (2007) studied the impact of agricultural technology adoption on poverty reduction in rural Bangladesh and found a robust and positive effect on farm households' wellbeing. Using the nearest-neighbor matching method he evaluated the causal effects of technology adoption on household wellbeing and his results show a significant and positive impact. The results show that on average the incomes of adopters were almost 30% higher than the incomes of non-adopters, which is the average difference between incomes of similar pairs of households belonging to different technological status.

Mignouna *et al.*, (2011) analyzed the impact of combating striga weeds through adopting imazapyr-resistant maize technology and organic fertilizers on farm income of smallholder maize producers in Western Kenya. The study used the tobit model to determine the factors influencing adoption of the technology. A gross margin analysis was used to estimate the difference in net returns in adopting and non-adopting households. The study found out that farming experience, risk-taking, education, the number of extension visits, gap between maize production and consumption, availability of seeds, membership in social group influenced adoption. There was a significant difference in gross margins, adopters had gross margins of KES 51, 753 per hectare per year while non-adopters got KES 26, 566. The study concluded that adoption of imazapyr-resistant maize technology and organic fertilizers was profitable for smallholder farmers and could have the potential to reduce poverty in striga-infested maize production areas in Kenya as climate change poses more threat of pest and disease incidence in crops. The study recommends more detailed studies on impact of adoption of improved crops varieties, which we delved on. The authors add some more scope in impact evaluation by using both propensity score matching and sensitivity analysis to account for unobserved heterogeneity.

The knowledge is important for formulating policies for adaptation planning that target resource-poor, smallholder farmers to enhance their adaptation to climate change through adoption of improved farming technologies to improve their main source of livelihood and give feedback to agri-oriented research organizations and the technology disseminating agencies in SSA.

3.0 MATERIALS AND METHODS

3.1 Study area

The study was conducted in semi-arid zones of Machakos County in South Eastern Kenya (SEK) namely Masinga, Mavoko and Mwala Wards. The areas were purposively selected for semi-arid semi-arid climatic conditions and dominant pigeon pea production. Machakos County receives bimodal rainfall with short rains season (March to May) and long rains from October to

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December (Gichangi *et al.*, 2015; Jaetzold *et al.*, 2006). The area is generally hot and dry receiving average annual rainfall of 614 mm of which 337 mm is received during the short rain season and 195mm during the long rain season (Gichangi *et al.*, 2015). Though both short and long rains seasons receive similar amounts of rainfall, short rain seasons are more reliable than the long rain seasons and therefore more important for crop production. The annual average temperature ranges between 29 degrees Celsius and 17.1 degrees Celsius (Jaetzold *et al.*, 2006; Gichangi *et al.*, 2015). The low rainfall and high evapo-transpiration due to higher temperatures make these locations more water stressed and riskier for crop production (Jaetzold *et al.*, 2006; Wambua et al., 2017).

3.2 Determination of sample size and sampling design

Following Kothari (2004) the sample size used in the study was computed as: $N = (z^2pq)/d^2$

Where: N is the desired sample size; z was set at 1.96 representing the standard normal deviation corresponding to 95 % confidence interval; p is the proportion of the population estimated to have a particular characteristic of interest e.g. proportion of households growing improved pigeon pea on their farms which was assumed to be 50 percent in this study (0.5). q = 1- p, is the proportion of households that could not be growing improved pigeon peas on their farms (0.5), d is the degree of accuracy. In this study, N= [3.842(0.5) (0.5)]/0.0025; N=384.2. The household data was gathered through a semi structured questionnaire.

3.3 Modelling impact of adoption on farm income

The study adopts the counterfactual approach and propensity score matching method to evaluate the impact of adopting improved pigeon peas on household net farm income. The main purpose for using matching was to find a group of treated individuals (adopters) similar to the control group (non-adopters) in all relevant pretreatment characteristics, where the only difference was that one group adopted improved pigeon pea varieties and the other group did not. We assumed that the source of the observed welfare effect of adoption of improved pigeon peas results in direct benefits accrued from increased productivity, marketable surplus and households' net farm income.

We adopted a counterfactual framework that an observed outcome has ex-ante two potential outcomes, one of adoption of the technology and another of not adopting that were denoted by y_{i1} and y_{i0} respectively. Taking the adoption status A=1 for adoption and A=0 for non-adoption for any household *i*, the impact of growing improved pigeon peas on household income was defined as: $y_1 - y_0$. However, either the impact of adoption on income (y_1) or impact on non-adopters income (y_0) can be observed on a household but not both at the same time (Rosenbaum and Rubin, 1983). The propensity score matching method that matches the treated and untreated cases on the propensity score rather than on the regressor was used to create the counterfactual situation (Rosenbaum and Rubin, 1983). The propensity score is the conditional probability of receiving treatment given covariate *X*, denoted by P(x) and expressed as $P(X) = (A_i{=}1|X)$. And the mean effect of adoption on the sub-population of adopters (average effect of treatment on the treated (ATT)) represents the impact of adoption on household income was expressed estimated as:

$$ATT = E\left(y_{1i} - y_{01}\middle|p(X)\right) = E(y_{1i}|p(X), A_i = 1) - E(y_{0i}|p(X), A_i = 0) \ldots\ldots\ldots\ldots\ldots \quad (1)$$

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Where $p(X)$ is the propensity score, X are the observable household characteristics$A_i = 1$, when the household is an adopter and $A_i = 0$ when the household is a non-adopter. The nearest neighbour (NNM) and kernel-based (KBM) matching methods were used in matching the propensity scores. We conducted a sensitivity analysis to verify if inferences about the impact of adoption of improved pigeon peas changed by existence of unobserved variables. Following Rosenbaum and Rubin (1985), the odds ratio that either of the two matched individuals would be adopters was expressed as:

$$\frac{1}{e^{\gamma}} \leq \frac{P(x_i)\left(1-P(x_j)\right)}{P(x_j)(1-P(x_i))} \leq e^{\gamma} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The odds ratio gives the ratio of the probability of adopting to not adopting. Varying the value of e^{γ}enables one to assess the sensitivity of the results to hidden bias and to derive the bounds ((Γ) of significance levels and confidence intervals. Data was analyzed using STATA 13.0 statistical package.

4.0 RESULTS AND DISCUSSION

The results report the general description of farmers' socio-economic and demographic characteristics, farmers' perception of improved pigeon pea as a climate change adaptation strategy, types of pigeon peas grown, factors determining the adoption and the impact of the adoption on household income and its implications.

4.1 Household characteristics

Household socio-economic and demographic characteristics are presented in Table 1

Table 1: Farm household characteristics

Variable	Adopters	Non-adopters
Proportion of sample (%)	33	67
If male gender of house head (%)	76	74
Average age of house head (years)	54	51
Farming experience of house head (years)	30	21
Household size (number)	6.6	5.3
Farm size (acres)	3.9	8.6
Own land cultivated (%)	35.8	15.8
Household aware of improved seeds (%)	100	46
Household access improved seeds (%)	100	07
Land under improved peas (acres)	0.74	0.00
Land under indigenous peas (acres)	0.25	1.05
Household has non-farm income (%)	82.4	64.2
Access agricultural extension services (%)	60.3	35.8
Access credit facilities (%)	24	10
Membership in farmers associations (%)	80	41
Access to climate information (%)	92	48

Adopters n= 127, non-adopters n=268

Adopters were defined as households that had grown improved pigeon peas during the cropping year of 2016/2017. Descriptive statistics disaggregated by adoption status in Table 1 show that 33% of the households were adopters. The sample consisted of about 75% male headed households indicating a patriarchal society (KNBS, 2018). The adopters had 9 more years of farming experience than the non-adopters. The adopters had an average land size of 3.9 acres of which 0.74 acres was under improved peas while non-adopters had 8.6 acres with 1.05 acres allocated to indigenous peas. Minority of the farmers interviewed owned land they tilled (36% adopters and 16 percent non-adopters) that reflects farmers limited control over land often an impediment to investment in adaptation strategies (Quan and Dyer, 2008). Nearly 100 percent of the adopters were aware of availability of improved peas and had access to the seed while 46percent and 7 percent of the non-adopters were aware of the seeds and had access respectively. Majority of the farmers had non-farm income (82 percent adopters and 64 percent non-adopters) which confirms diversification of household income sources as a risk management (Claessens *et al.*, 2012). There was low farmers access to formal credit facilities for agricultural development (24 percent adopters and 10 percent non-adopters) despite the financial low financial status that constraints smallholder rural farmers in adopting adaptation strategies. Eighty percent of adopters and 41 percent non-adopters had membership in farmers associations, 92 percent of adopters and 48 percent of non-adopters had access to climate change information.

4.2 Farmers' perception on production of improved peas as adaptation to climate change

Table 2: Farmers' perception on improved pigeon peas in adaptation to climate change

Variable	Adopters (%)	Non-adopters (%)
Perceived improved peas was adaptation to climate change	94	76
Perceived adaptation-improved peas drought tolerant	93.6	70
Perceived adaptation-improved peas early maturing	92	75
Perceived adaptation-improved peas increase yield	84	68
Perceived adaptation-improved peas pest diseases tolerant	80	54

Production of improved pigeon peas was perceived as an adaptation strategy to climate change in 94 percent adopting and 76percent of the non-adopting household (Table 2). About 94 percent of adopters and 70 percent of non-adopters perceived that improved peas had drought tolerance, 92 percent adopters and 75percent non-adopters perceived early maturing attribute, 80 percent and 54 percent perceived that the peas had pest and disease tolerance. The increase in atmospheric temperature with reduced, variable rainfall causes both biotic and abiotic stress to pigeon peas in semi-arid Kenya (Kwena *et al.*, 2018) and perception and /or potentials to avert the adverse effects through production of improved crop varieties fosters adoption to increase productivity. The results confirms effort of agricultural researcher to mitigate effects of climate change to increase productivity within a finite natural resource basis and maintain food security in the face of population growth and climate change (Miriti *et al.*, 2012).

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Table 3: Improved pigeon pea varieties grown

Variety	% producers	Mean acres	Min. acres	Max. acres	Std. dev
KARI mbaazi1	8.6	0.906	0.20	3.0	0.461
KAT6/80	7.2	0.652	0.25	2.0	0.453
ICPL87091	7.2	0.666	0.25	4.0	0.628
ICEAP00554	3.6	0.800	0.25	2.5	0. 730
KARI mbaazi2	3.0	0.625	0.20	2.75	0. 628
ICEAP00557	2	0.581	0.25	2.25	0.551
ICEAP00777	1.4	0.522	0.20	2.0	0.584

n=385, 33% adopted improved varieties, 60% grew indigenous peas only, 7% did not grow pigeon peas

About 12percent of the households sampled had grown KARI mbaazi1 on average acreage 0.91 acres (std. dev 0.461), both KAT6/80 and ICPL87091 were grown by 10 percent of the farmers (Table 3). There was a relatively lower adoption of ICEAP 00557 (3percent) and ICEAP 00777 (2percent) on average 0.6 acres. The higher adoption of KARI mbaazi1, KAT6/80 and ICPL87091 was probably due to their early maturing and high yielding attributes while lower adoption of KARI Mbaazi2, ICEAP00557 and ICEAP00777 varieties could be due to their long maturity period of 8-9 months. The indigenous peas were grown by 49% of the farmers (average acreage 1.05) and 5percent of the farmers did not grow any pigeon peas. The results implied that the indigenous varieties were still popular in semi-arid areas of Machakos County probably indication of some constraints in adopting the improved varieties.

4.3 Factors determining adoption of improved pigeon peas

Table 4: Logit estimates of Propensity scores of improved pigeon pea producing farmers

Variable of household head	Coef	Std. Err.	z
Gender (1= Male, 0= Female)	0.126	0.324	0.39
Education (years)	0.060	0.117	0,513
Experience (years)	0.143	0.049	2.92**
Family size	0.462	0.317	1.46
Non-farm income	0.248	0.379	0.65
Farm size	-0.726	0.374	-1.94
Own land cultivated	0.319	0.301	1.06
Access agric extension services	0.255	0.089	2.88**
Access to improved seed	1.703	0.497	3.43***
Access credit for farming	0.092	0.169	0.54
Perceives adaptation	0.872	0.305	2.86**
Access climate information	1.158	0.226	5.12***
Member of farmers association	0.745	0.199	3.74***
Constant	-1.708	0.296	-5.77***
No. of observations	385		
$LR\chi^2(13)$	310.26		
Pseudo R^2	0.434		

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Note: *Significant at the 10% level; **significant at the 5%; ***significant at the 1% level.

Table 4 shows that household heads with more years of farming experience, having access to agricultural extension services and perceived that production of the improved pigeon peas was an adaptation strategy to climate change were more likely to adopt the technology than the reverse. The variables were statistically significantly at 5 percent level. Households with access to: improved pigeon pea seed, climate information and that participated in farmers association were more likely to adopt the technology than those who did not. The variables were significant at 1 percent level. Male headed households were positively associated with adoption thought the variable was not significant. Those with smaller farm sizes were more likely to adopt than those with large farm holdings. Households with more members, with off farm income, that owned the land they tilled and had access to credit services for livestock development were more likely to grow improved pigeon peas than those without. The Pseudo $R^2$was 0.43 indicating that the regressor variables explained 43 percent probability of adopting the technology.

Table 5: Pigeon pea production adaptation to climate change

Adaptation strategy	Adopters %	Non-adopters %
Various varieties of pigeon peas	94	76
Disease tolerant varieties	65	90
Early maturing varieties	92	22
High yielding varieties	88	46
Practice mixed farming	96	98
Soil and water Conservation	74	67
Changing planting dates	45	49
Manure application	04	02

Adopters n=127, non-adopters n=268

Different varieties of pigeon pea were grown as a climate change adaptation strategy in 94 percent of the adopting households and in 76 percent of the non-adopting ones (Table 5). A larger proportion of adopters (92%) compared to 22 percent non-adopters grew early maturing varieties in adapting to climate change, the results were similar with production of high yielding varieties (88% vs 46%). This could probably be due to preference of the disease tolerance attribute. Mixed farming was practiced in 96 percent and 98 percent adopting and non-adopting households respectively. Soil and water conservation was practiced in 74 percent and 67 percent in the two groups correspondingly. Surprisingly less than 5 percent of the farmers used manure on farm indicating limited application of soil fertility enhancing practices in pigeon pea production despite high levels of soil degradation in Machakos County (Kwena *et al*., 2018).

4.4 Impact of adoption of improved pigeon peas on households' net farm income

The results in Table 6 portray a higher returns in adopting group relative to non-adopters in both the matching algorithm. From the nearest neighbor matching method, adopters incurred a cost of KES 29,804 per acre per year, while non-adopters had KES 21,675. The column under Average treatment effect of the treated (ATT) shows that adopters experienced an increase in total variable cost of production relative to non-adopter of KES 8,141 per acre per year that was significant at 5% level. There was a 22 man-days increase in labour demand for adopters. Dry and green pigeon pea yield increased significantly (5%) by 250kg and 156kg per acre per year respectively. The adopters also had a significant increase in gross revenue KES 27,900 per acre per year that was and the net revenue was KES 18,631. Though the cost of adopting the technology significantly increased, the resultant revenue was higher than in non-adopting households the cost of production is still a major adoption constraint in resource-poor households and necessitates designing of innovation that reduce the cost of production.

Table 6: Impact of adoption of improved pigeon pea on Net farm income

Outcome variable/matching algorithm	Adopter	Non-adopters	ATT	Critical level hidden bias (Γ)
	Mean outcome		Difference	
NNM algorithm				
Cost of production (KES)	29,804	21,675	8,141(2.25)**	1.45-1.50
Labour demand (Manday)	121	100.5	22(2.06)**	1.25-1.30
Yields of dry peas (kg)	570	320	250(2.31)**	1.50-1.55
Yields of green peas (kg)	358	202	156(2.98)**	1.45-1.50
Gross Revenue (KES)	61,700	33,790	27,900 (3.14)***	1.95-2.00
Net income (KES)	30,710	12,075	18,631(2.77)**	1.60-1.65
KBM algorithm				
Cost of production (KES)	29,470	21,590	7,902(3.31)***	1.75-1.80
Labour demand (Md)	125	102	22(1.86)**	1.20-1.25
Yields of dry peas (kg)	536	300	239(2.77)**	1.55-1.60
Yields of green peas (kg)	371	224	145(2.42)**	1.50-1.55
Gross Revenue (KES)	63,568	36,903	26, 673(3.33)***	2.00-2.05
Net income (KES)	32,300	12,870	19,432 (2.67)**	1.55-1.60

NNM, KBM are nearest neighbor matching and Kernel-based Matching, KES is Kenya Shillings, Md are Man days, kg is weight in kilogram, *,**, ***, represent statistical significance at the ten percent, five percent, and one percent levels, respectively; t-values (in parentheses) are calculated from bootstrapped standard errors.

Column 5 of Table 6 presents the sensitivity analysis for the presence of hidden bias in the determinants of adoption of improved pigeon peas. The bounds of the critical levels were calculated for outcomes between the adopters and non-adopters that were significantly different from zero (Rosenbaum and Rubin 1985). The lowest value of Γ was 1.20–1.25, and the largest critical value is 2.00–2.05. For example under the nearest neighbor matching algorithm, the results on the impact of growing improved pigeon peas on net farm income, the sensitivity analysis shows that at a level of Γ = 1.65 no hidden bias due to an unobserved confounder exists. This implies that if the odds of an individual being an adopter of improved pigeon peas are 1.65 times higher (65%) because of the unobserved covariate, despite being identical on the matched observed covariate, there may be a change in the inference (Keele 2010). The results mean the inference on estimated effects will not be altered even in the presence of large amounts of unobserved heterogeneity among the adopters and non-adopters.

4.5 Discussion

Majority of the farmers interviewed perceived production of improved pigeon pea as an adaptation to climate change. Climate change is predicted to increase atmospheric temperatures, increase, reduce crop growing seasons, dry and degrade soils, increase pest and disease incidence and cause shifts in suitable areas for growing crops in semi-arid areas of Sub-Saharan Africa and therefore reducing crop yields (Boko *et al.*, 2007; Niang *et al.*, 2014). Farmers perceived that drought, pest and disease tolerance, early-maturing and high yielding characteristics of improved pigeon peas had the potentials of reducing climate change risks on food security and household income. The increase in crop yield especially in improved pigeon peas could be attributed to increased number of pods and seasonal harvest (twice a year) relative to the once-a- year harvest from the long-maturing indigenous varieties that was the relative advantage of the technology. The results confirm high yielding attribute of improved pigeon peas (Kwena *et al*., 2018; Olubayo *et al.*, 2007). Early harvests helps households' get through the hunger period before harvest when the previous year‘s grain supplies have been exhausted. Adrian *et al* (2005) and Walton *et al*, (2008) found out that farmers' opinion on relative benefits of new technologies and the expected gains greater than those of the other known technologies influence their positive perception and adoption of the technology. Realistically and perceptibly, rational farmers do not want to get losses in their investments and therefore, the perception of the technology as an adaptation to climate change was higher when expected results of adoption was seen in terms of the positive attributes of the improved varieties. Farmers' perception of a technology influences its adoption (Mekoya *et al*., 2008; Mottaleb, 2018), this was evident from a larger number of adopters who grew early-maturing varieties (32% of the 46% adopters). Farmers' positive perception of a technology is critical for its adoption and scaling up to ensure sustainability in production and development of agricultural sector that is resilient to climate variability and change. In addition to growing early maturing, drought, pest and disease tolerant varieties of pigeon peas in adapting to climate variability and change, the farmers also practiced mixed farming in diversification of farming enterprises and manage climate-related risks. Soil and water conservation has recommended as a soil moisture improvement practice to diminish the common water stress in semi-arid area. Surprisingly, there was limited manure application on farm even though South Eastern Kenya is an agro-pastoralist zone. The phobia of plant scotching by manure during scarcity of soil moisture is common in semi-arid areas limits its application on farms (Cooper *et al*., 2008). There is need for farmers' capacity building on soil fertility management in drylands as integral component of adaptation to climate change (Vanlauwe *et al.*, 2006; 2015; Zingore *et al*., 2007).

The results indicate that households with small farm sizes and large family sizes were more likely to grow improved peas. This explains the astuteness of farm decision makers to efficiently utilize the small land resource to reap maximum benefits to meet the needs of their large families. Access to pigeon pea seed positively influenced adoption of the technology. The results are in line with FAO (2014) that farmers' access to improved seed is concomitant to increased adoption of improved varieties and enhanced food security in resource-poor smallholder farming systems in developing countries. Simtowe *et al.*, (2012) also reported farmers' adoption of improved pigeon pea varieties in SEK and in Tanzania (Simtowe *et al.*, 2016) was contingent to access to improved seed. The recurrent drought in SEK region and resultant crop failure (GoK, 2015) is a common precursor to exhaustion of seed stock in most resource-poor households. This is due to the tendency of the households converting the seed into food whenever there is drought and hunger. Frequent replenishment of seed stock by increasing its availability and improving farmers' access in terms of location and affordability is thus inevitable if production of improved pigeon pea varieties in SEK is to be increased. Farmers' access to climate change information significantly influenced farmers' adoption of improved pigeon peas. The results are similar to those of Gichangi *et al.,* (2015) on importance of accessing climate change information to influence adoption of adaptation strategies to climate change in semi-arid Eastern Kenya. Farmers' access to climate change information is crucial for farm planning especially as the SEK region receives erratic rainfall.

Household heads with membership in farmers association were more likely to adopt improved pigeon peas than non-members. This could be attributable to farmer group meetings that form local fora for interactive knowledge exchange which enhances adoption of agricultural technologies. Rural farmers access information regarding production, expected yields and market information from neighboring farmers or from members of a farmer group influences farmers input use. The form and language through which the information is passed from one farmer to the other enhances adoption of technologies among rural farming communities. Involvement in producer marketing group enhances the farmers' negotiation and marketing skills to improve their income alongside giving them a voice to lobby for support from the County Government.

The results showed a significant increase in cost of production for adopters of improved pigeon peas with a resultant yield increase. The cost of production consists of expenses of acquiring farm inputs like seed and pesticides. Though access to credit was positively associated with adoption of improved pigeon peas, there was low utilization of credit among the farmers. Majority of the farmers in semi-arid Kenya lack formal land ownership that is often a precursor to limited access and utilization of credit facilities that constraints smallholder farmers' adaptive capacity (Carabine and Simonet, 2018). The results portrayed a significant increase in crop yields that emanated from use of improved varieties that were high yielding. The results are similar with those of Birthal *et al.*, (2012) who attributed 33–46% farm income increase from adopting drought-tolerance groundnuts as an adaptation to climate change in Anantapur district a semi-arid region in India as clear and compelling. The results depict a significant yield difference between the adopters and non-adopters, which suggests that with adequate support of smallholder agriculture and market development in addition to adoption of climate risk-reduction practices, semi-arid areas could significantly increase pigeon pea crop production. Increase in crop yields means that the households experience both nutritional and commercial benefits. The results are corroborate those of Audu and Aye (2014); Awotide *et al., (*2015)) and Nguezet *et al*., (2011) that adoption of agricultural technologies increased yield contributing to enhancement of household farm income. Most pigeon pea farmers in SEK are resource poor and therefore high net farm income from adoption of the improved varieties should be an incentive for increased production.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Production of improved pigeon peas was perceived as a strategy to enhance the farmers resilience to climate change seen through the lens of reduced biotic and biotic stress in terms of drought, pest and disease tolerance and early maturing. The results on descriptive analysis of the farmers showed that 7% of the non-adopters had access to improved seed, lack of access to improved seeds by farmers' constraints adoption. This highlights the need for the County and National Governments to facilitate farmer groups to produce seed through training and linkage to the Plant Health Inspectorate Services for certification of seed production to improve availability of seed at community level. It was confirmed that production of improved pigeon peas increased households' net farm income and that the results were insensitive to hidden bias. Rational farmers are likely to invest in a technology that yields positive net returns and therefore establishment of efficient markets that enhance access to market information is key in facilitating response strategies.

Recommendations

Farmers' adaptive capacity could be strengthened by the County Government investment in agricultural products value chain development to provide information spanning from production to marketing of farm produce. Provision of market information can alleviate information asymmetry that is prevalent in rural areas and which exposes the smallholder farmers to exploitation by brokers/middlemen. Adopters of improved pigeon peas incur a high cost of production emanating from high price of certified seed, pesticides and labour requirement. High expense on pesticides highlights the need to reduce pest infestation. There is need for both the National and County Governments to invest in research on biotechnological innovations to produce pest tolerant varieties and farmer capacity building on safe use of pesticides to limit environmental pollution and use of soil fertility enhancing inputs like manure should be encouraged to limit land degradation that is common in semi-arid areas and which is bound to increase with climate change. Improving farmers' access to improved seed and establishment of efficient market of farm products can enable farmers to contribute to rural food security and sustainable adaptation planning.

Abbreviations

ASALs: Arid and Semi-arid Areas; ATE: Average Treatment Effect; ATT: Average Treatment Effect on the Treated; CSA: Climate Smart Agriculture; FAO: The Food and Agriculture Organization of the United Nations; FAOSTAT: FAO Statistics; GoK: Government of Kenya; ICRISAT: International Crops Research Institute for the Semi-Arid Tropics; IPCC: The Intergovernmental Panel on Climate Change; KALRO: Kenya Agricultural and Livestock Research Organization; KBM: Kernel-based Matching algorithm; KES: Kenya shillings; NNM : Nearest Neighbor Matching algorithm; SEK: South Eastern Kenya; SSA: Sub-Saharan Africa.

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