Gendered farmer perceptions towards soil nutrition and willingness to pay for a cafetiere-style filter system for soil testing *in-situ*: evidence from Kenya

Philip Kamau,[a] Ibrahim Ndirangu,[a] Samantha Richardson,[b] Nicole Pamme,[c*] Jesse Gitaka[a*]

[a] Directorate of Research and Development, Mount Kenya University, P.O. Box 342-01000, Thika, Kenya

[b] School of Natural Sciences, University of Hull, Cottingham Road, Hull HU6 7RX, UK

[c] Department of Materials and Environmental Chemistry, Stockholm University, SE-106 91 Stockholm, Sweden. nicole.pamme@mmk.su.se

Abstract

Soil nutrition is a key pillar in agricultural productivity. However, point-of-need testing for soil nutrition is not readily available in resource limited settings such as Kenya. We set out to study the perceived needs for soil testing among farmers in this country. A group of 547 farmers from Murang'a and Kiambu counties were recruited through multistage sampling and helped in assessing the attitudes and willingness to pay (WTP) toward a prototype technology for *in-situ* soil nutrition surveillance based on a cafetiere-style filter system for extraction and a paper-based analytical device (PAD) for nutrient readout. Considerations for the prototype to measure nutrient levels *in situ* included aspects of affordability, sensitivity, user-friendliness, and portability as well as willingness of farmers to make their own soil data publicaly available. The study revealed that currenlty extremely few farmers carry out soil testing. The cost of testing and that fact that testing centers are often far from the farmers are among the main reasons contributing to farmers not testing their soils. Farmers are generally willing to make their soil data publicly accessible especially with extension officers. The contingent valuation method (CVM) showed that uncontrolled WTP had a 94.24% premium above the Kes 1000 that is incurred by using the existing rapid testing method. Factoring the control variables and disaggregating the model into gender categories the findings showed that youth, women, and men had WTP values of Kes 1612.53, Kes 1558.68, and Kes 1504.83 respectively which indicates that farmers can indeed pay for convenience to test their soils *in situ*. The study concludes that women and youth should remain the subject of policy focus. Extension

education can enhance the improvement of agricultural productivity if the government restores the department's effectiveness.

1. Introduction

Poor soil nutrition is a major factor that negatively influences agricultural productivity in sub-Saharan Africa (SSA) (Binswanger-Mkhize, 2009; Kihara et al., 2020; OECD/FAO, 2016; Rahman & Zhang, 2018; Richards et al., 2016; Stewart et al., 2020; Zingore et al., 2015). Zingore et al. (2015) documented that soil malnutrition affects over 350 million hectares. Tittonell et al. (2008) report that SSA soils are mostly nitrogen (N) and phosphorous (P) deficient. Legumes yield below 1 ton per hectare (t ha^{-1}) despite their capacity to produce over 2 t ha^{-1}. Similarly, cereals yield approximately 1.5 t ha^{-1} with a possibility of producing above 5 t ha^{-1} (Zingore et al., 2015). With the dwindling farm sizes in SSA (Lewis, 1985; Makokha et al., 2001; Ovuka, 2000) and climate change (AGRA., 2014; Binswanger-Mkhize, 2009), we must look for all possible agricultural intensification strategies to ensure high production that serve the urban, rural populations, and the export market. One of the enabling techniques is to enhance soil fertility to improve agricultural productivity but few people currently carry out soil testing due to high cost of soil testing and long distances to the laboratories (Middendorf et al., 2017).

Trained personnel conduct laboratory soil test procedures (Dudala et al., 2020). They use reagents to extract available ions from the soil. UV/vis absorption spectroscopy based methods, or Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) are a common detection methods to measure ion concentrations (Smolka et al., 2017). These laboratory soil testing procedures are carried out by trained personal and the workflow takes some time, and thus farmers need to wait before they get their results.

Many farmers in Sub-Saharan Africa (SSA) lack soil testing knowledge, lack dependable testing services or adequate laboratories (Middendorf et al., 2017). The national agricultural research organizations offer soil testing services. Other service providers include private companies, for instance, Crop Nutrition Laboratory Services Ltd (CROPNUTS), and universities, for instance, Makerere University, Uganda, and the University of Nairobi, Kenya (Chianu et al., 2012; Dimkpa et al., 2017). The high cost of soil testing and the extremely sparse distribution of laboratories discourage peasant farmers from accessing soil testing services

(Dimkpa et al., 2017). Current information on soil nutrients provides an erratic representation of heterogeneous environments because soil testing facilities are relatively inaccessible to smallholder farmers (Hengl et al., 2017).

The unreliable laboratory services in SSA have prompted the development of rapid methods that enable soil testing on-site (Motsara & Roy, 2008). This includes non-liquid spectroscopy-based nutrient testing systems that have gained acceptance in SSA (Dimkpa et al., 2017). The AgroCares nutrient scanner (AgroCares, NL) has expanded usage in Eastern Africa, particularly in Tanzania, Rwanda, Burundi, Kenya, and Uganda on account of its soil testing rapidity where soil nutrients results and recommendations for soil improvement are given to farmers in a few hours (Vernooij, Wals, & Van Der Lee, 2015). Spectroscopy-based scanners are expensive to buy but they have a long work life and are reusable. Since the scanners use buttons, it is relatively easy to train farmers to operate them compared to the colorimetric methods with reagents. Despite all the advantages of these AgroCares scanners in helping farmers test their soil onsite, their initial cost of several thousand US dollars is above affordability by many SSA farmers (https://webshop.agrocares.com/agrocares-scanner-device.html).

The rising literature on willingness to pay (WTP) and uptake of new agricultural technology often does not take into consideration factors that influence gender-specific needs and preferences among men, women, and young farmers (Ahiale, Balcombe, & Srinivasan, 2019; Kahwai et al., 2021; Mottaleb, 2018; Omotayo et al., 2021; Paudel et al., 2019; Shee, Azzarri, & Haile, 2020; Ulimwengu & Sanyal, 2011; Verma et al., 2020; Yussif, Obeng, & Ansah, 2017). Also, most of the studies that address WTP (Amponsah et al., 2016; Kahwai et al., 2021; Kamau et al., 2018; Omotayo et al., 2021; Paudel et al., 2019; Ulimwengu & Sanyal, 2011; Verma et al., 2020; Yussif et al., 2017) do not consider gender-specific factors that might affect their willingness and perceived needs for the new technologies. Framers that are women and young adults (between 18-35 years) are faced with greater challenges in affording and adopting new technologies than their male counterparts (FAO, 2017; Ndeke et al., 2021; Rola-Rubzen et al., 2020). This is in addition to low access to agricultural training and education, low assets such as livestock, farm machinery, and implements, and biased access to credits (Doss et al., 2018; Glazebrook, Noll, & Opoku, 2020). Lack of attention to gender-specific needs causes gender inequalities in technology adoption which may be attributed to low uptake of new technologies across the agricultural sector (Huyer, 2016; Jost et al., 2016). This is made worse by a general exclusion from decision-making on matters pertinent to agriculture (Agarwal, 2001; Ndeke et al., 2021).

In this study we aim to invesitagate current practises and perceived needs of local farmers and key stakeholders concerning soil analysis and health. Linked to this we will explore WTP for low cost technologies that would enable a farmer to monitor soil nuitrition on their own land. Unlike previous studies we will shall investigate the persons that may be trusted by different gender groups with their soil nutrition data. As such, in case of a successful development of an on site technology, the identified persons will be instrumental for targeted technology dissemination. The study will also scope attitudes and motivations of stakeholders, *i.e.* farmers, and government officers in the democratization of soil data in Kenya.

2. Materials and methods

2.1. Study area

The survey was conducted in Kiambu and Murang'a counties of Kenya where Gatundu south and Kandara sub-counties were covered. Agricultural activities in both study sites fall under different agro-ecological zones (AEZs) ranging from AEZ I (Agro-Alpine) to AEZ III (Medium Potential) (Lewis, 1985; Republic of Kenya, 2014). Further description of the study area is captured in the supplementary information (**ESI 1**).

2.2 Sampling design and sample size

Ethical approval for the study was granted through the Mount Kenya University Ethical Committee, ref MKU/ERC/1797. A multistage sampling procedure was employed to estabilish the study area and sample size. The choice of these counties was informed through discussion with local agricultural officers, taking into account the proximity to the largest food market (Nairobi) and high land fragmentation due to population growth and soil fertility loss from suboptimal use of fertilizers in a set-up of continuous cropping and climate change (Lewis, 1985; Makokha et al., 2001; Ovuka, 2000). A similar approach was used to select the Ndarugu and Ruchu wards of Gatundu south and Kandara sub-counties, respectively. Extension officers of Ndarugu and Ruchu agricultural wards supplied a list of 4,500 and 4,000 farmers, respectively, from male and female-headed households from all villages. In our study, households became the basic element of the survey and were randomly selected.

The sample size of the study was acquired using Cochran's formula (Cochran, 1963) and further explained by (Israel, 1992). The formula is presented in **equation 1**;

$$n = \frac{Z^2(pq)}{e^2} \approx \frac{1.96^2 * 0.5 * 0.5)}{0.425^2} \approx 532 \text{ households} \quad (1)$$

where n = sample size, Z = standard error associated with the chosen level of confidence, p = estimated proportion of an attribute present in the population (variability), $q = 1 - p$, and e = acceptable sample error. Since there is no credible documented variability of farmers in both counties, the level of precision p is assumed to be maximum (0.5). The value of Z (at 95% confidence level) and e used were 1.96 and 0.425, respectively. The sample size was approximately 532 households and probability proportion to size criteria allotted 282 and 250 households to Ndarugu and Ruchu respectively. We scaled up the sample size to 547 (**Table 1**) to absorb the risk of possible spoiled questionnaires that could arise from misinformation or non-response. In the Ndarugu ward, the youth category comprised 46 male-headed and 10 female-headed households, while in the Ruchu ward, the composition was 31 male-headed and 7 female-headed households.

Table 1. Sampled male and female-headed households sampled per sub-county

Ward	Men (35+)	Women (35+)	Youth (18-35)		Total
			Female	Male	
Ndarugu	172	62	10	46	290
Ruchu	170	49	7	31	257
Total	342	111	17	77	547

2.3 Data collection and processing

The cross-section survey used a semi-structured questionnaire (**ESI 2**) to collect household data including institutional factors, socioeconomics factors, demographics, existing farming practices, attitudes towards a portable *in situ* soil surveillance technology system, and soil testing knowledge. The formulated questionnaire was programmed to use Open Data Kit (ODK) software for electronic data collection (Kamau et al., 2018; Ndeke et al., 2021). Before the data collection exercise began, training of enumerators was done and the questionnaire was pretested using 41 households at the Ithiru ward of Kandara in similar AEZ as the study sites. All the enumerators were trained before the administration of the questionnaires.

Cleaning of data was carried out with SPSS v.23 which was also was used for the actual analysis along with STATA v.14. The analysis was performed through disaggregation of findings into gender. For continuous variables, t-tests were conducted to identify the significant differences and Chi-square tests to determine differences amongst categorical variables. The econometric model, double bounded dichotomous choice – contingent valuation method (CVM) was analyzed using STATA.

2.4. Theoretical foundation and analytical framwework

2.4.1 Theoretical foundation

An acceptable scientific method of evaluating the non-market products' (good and service) value is via the use of monetary terms technique. The valuation gives a reflection of the perceived impact that the products might have on the welfare of consumers contingent on the products being in the market. Theoretically, the economic value of a product can be measured in four ways, holding utility constant, as proposed by (Hicks, 1943). The welfare measurement according to Hicksian theory entails assessment of compensating variation and compensating surplus; a method that measures losses or gains in comparison to the primary utility level of a market product. The theory also measures equivalent surplus and equivalent variation to assess losses and gains attached to a prospective alternative level of utility. Measures of variation are only used for changes in product price such that individuals respond by varying the products of interest (Mitchell & Carson, 1989). Measures of surplus apply when the changing factor is the product quality or quantity but consumers can just purchase fixed quantities (Freeman, 1994). Freeman (1994) alludes that most applications of Hicksian theory entail fixed variations (increases and decreases) in the quality and quantity of non-market products. In our case, we adopt the measurements of human welfare via Hicksian welfare surplus, specifically the compensating surplus as derived in **equation 2**.

$$u(Q^0, M^0) = u(Q^1, M^0 - CS) \tag{2}$$

where u is the indirect utility function, Q is the non-market product, M is income or money, and CS is the compensating surplus. This means that farmers will be willing to accept /pay for soil nutrition surveillance *in-situ* technology as an indicator of the acquisition of positive change.

2.4.2 Econometric modeling for assessing willingness to pay for portable anlayis system.

The willingness to pay for for an *in situ* soil nutrition surveillance tool was measured using an econometric model known as the double bounded contingent valuation method (CVM) (Amponsah et al., 2016; Eom, Oh, Cho, & Kim, 2021). Research in this sense evaluates products or services not yet on the market, so farmers were asked to value them based on there being a market (Kimenju & De Groote, 2005). The object of this analysis was to determine if farmers would be willing to pay for the convenience value of a rapid soil diagnostics system that would enable onsite testing with reference to the current price of approximately Kes 1000 using the existing laboratories. The CVM model developed for this study is elaborated in the supplementary section **ESI 3** and variable specifications are in **ESI 4** (**Table S1**). The contingent valuation method (CVM) model was tested for multicollinearity to identify if the explanatory variables were inter-correlated. We used the Variance Inflation Factor (VIF) such that $VIF_i = 1/1 - R_i^2$, where R_i^2 represents an R^2 of an artificial Ordinary Least Square and assumes that each explanatory variable is dependent on others. The individual and mean VIF values were below 10 as presented **ESI 5** (**Table S2**) implying that multicollinearity was not an issue with the model data.

3. Results and discussions

3.1 Gendered farmer and farm characteristics

Out of the 547 farmers surveyed, the largest group (46.4%) had only attained up to primary education followed by 34.6% who had secondary education. Most (82.1%) of the farmers received a low monthly income (Kes 1 – 15 000), including 92.8% of women sampled. Forty two percent of the household heads were above the age of 55. More youth adults and men earned off-farm income compared to their female counterparts, and the difference was statistically significant ($p<0.01$). Most (92.3%) of the farmers own title deeds for land ownership. More men than women and young adults had irrigation to their crop production. Regarding asset ownership, the young adults had a statistically lower values of assets than the men and women gender categories. Women significantly received more extension contacts with farmers than men and young adults. Distance to the market did not significantly differ among the gender groups. Men (>35 years) cultivate larger crop area than women and young adults. Ownership of livestock was not different among the gender groups. The average household size was about four persons per household. The findings in this sub-section are summarized in in the supplementary materials section (**ESI 6, Table S3**).

3.2 Existing practices across genders

We studied the farmers' knowledge of soil dynamics (*e.g.* pH, soil losses, and nutrients), and perceived nutrients levels in their farms (**Table 2**). The survey revealed that more young farmers (72.3%) had prior knowledge of soil pH compared to older men (57%) and women (55.9%). The majority (66.7%) of the farmers considered their soils fairly fertile.

Table 2. Gendered descriptive statitics for soil nutrition knowledge

Variable	Pooled (N=547)	Men (N=342)	Women (N=111)	Youth (N=94)	
	Freq (%)	Freq (%)	Freq (%)	Freq (%)	χ^2
Knowledge					
of soil nutrients	252 (46.1)	153 (44.7)	47 (42.3)	52 (55.3)	4.102
of soil pH	325 (59.4)	195 (57)	62 (55.9)	68 (72.3)	7.803**
of soil loss	510 (93.2)	322 (94.2)	101 (91)	87 (92.6)	1.412
Perceived nutrients levels on own farm					
Very poor	5 (0.9)	4 (1.2)	0	1 (1.1)	9.223
Poor	58 (10.6)	45 (13.2)	7 (6.3)	6 (6.4)	
Fair	365 (66.7)	218 (63.7)	78 (70.3)	69 (73.4)	
Good	113 (20.7)	72 (21.1)	24 (21.6)	17 (18.1)	
Very good	6 (1.1)	3 (0.9)	2 (1.8)	1 (1.1)	

3.3 Existing practices to mitigate soil fertility losses across genders

We investigated the existing practices to mitigate soil fertility losses (**Table 3**). A slight majority (58%) used inorganic fertilizers. Diammonium phosphate (DAP) and NPK (17:17:0) were the two most used basal fertilizers at 20.8% and 16.1%, respectively. Calcium ammonium nitrate (CAN) was the most used top-dressing fertilizer. Other farmers used farmyard manure (FYM) (37.9%), compost manure (1.5%), and industrial organic fertilizers (0.2%) among other minor methods (0.8%) such as residues, crop rotation, and crop cover. Despite the majority (59.4%) of the farmers knowing that their soils could be acidic, only approximately 30% took measures to control the condition. A proportion of 17.2% of the farmers who controlled low pH levels mixed FYM with ash, while another 8.8% used lime, especially on their coffee and tea farms. An interesting observation is that a minority (1.8%) of farmers use organic manure as a pH control strategy. This practice however has been reported to possibily contributing to low pH in acidic soils (Whalen, Chang, Clayton, & Carefoot, 2000).

Table 3. Gendered descriptive statitics for the existing fertility management practices

Variable	Pooled (N=547)	Men (N=342)	Women (N=111)	Youth (N=94)	
	Freq (%)	Freq (%)	Freq (%)	Freq (%)	χ^2
Mitigation of soil fertility loss					
Inorganic fertilizers	317 (58)	197 (57.6)	76 (68.5)	44 (46.8)	28.882**
Basal fertilizers					
DAP	114 (20.8)	69 (20.2)	26 (23.4)	19 (20.2)	9.335***
NPK (17:17:0)	88 (16.1)	62 (18.1)	18 (16.2)	8 (8.5)	
NPK (23:23:0)	20 (3.7)	12 (3.5)	6 (5.4)	2 (2.1)	
NPK (25:5:5)	17 (3.1)	11 (3.2)	4 (3.6)	2 (2.1)	
NPK (25:25:25)	15 (2.7)	6 (1.8)	7 (6.3)	2 (2.1)	
NPK (20:20:0)	7 (1.3)	3 (0.9)	2 (1.8)	2 (2.1)	
Mavuno basal	6 (1.1)	4 (1.2)	2 (1.8)	0	
Others	4 (0.8)	4 (1.2)	0	0	
Topdressing fertilizers					
CAN	42 (7.7)	25 (7.3)	11 (9.9)	6 (6.4)	0.779
UREA	4 (0.7)	1 (0.3)	0	3 (3.2)	
Manure	217 (39.7)	135 (39.5)	33 (29.7)	49 (52.1)	
Compost	8 (1.5)	8 (2.3)	0	0	
Crop cover, residues, rotation	4 (0.8)	1 (0.3)	2 (1.8)	1 (1.1)	
Industrial organic fertilizer	1 (0.2)	1 (0.3)	0	0	
Control of soil pH					
No control	379 (69.3)	242 (70.8)	76 (68.5)	61 (64.9)	32.841**
Wood ash	94 (17.2)	42 (12.3)	28 (25.2)	24 (25.5)	
Liming	48 (8.8)	38 (11.1)	5 (4.5)	5 (5.3)	
Organic manure	10 (1.8)	9 (2.6)	0	1 (1.1)	
Fallowing	7 (1.3)	5 (1.5)	1 (0.9)	1 (1.1)	
Mulching	5 (0.9)	3 (0.9)	1 (0.9)	1 (1.1)	
Crop rotation	4 (0.7)	3 (0.9)	0	1 (1.1)	

*** and ** are statistical significance at 1% and 5% respectively

3.4 Soil analysis needs

A minority (1.5%) of the farmers currently have their soil tested for nutrients and pH. Only 4.4% of the sampled farmers were aware about existing rapid soil diagnostic technology in which they were referring to the AgroCares Nutrient Scanner (**Table 4**).

Table 4. Current soil testing capacity and awareness of rapid tsting technologies

Variable	Pooled (N=547)	Men (N=342)	Women (N=111)	Youth (N=94)	
	Freq (%)	Freq (%)	Freq (%)	Freq (%)	χ^2
Soil testing	8 (1.5)	8 (2.3)	0	0	4.866*
Aware of any existing rapid soil test method	24 (4.4)	18 (5.3)	4 (3.6)	2 (2.1)	1.932

Farmers cited different reasons for not testing their soils, for instance lack of knowledge about soil testing sucgh as not knowing who tests the soil, what is tested in the soils, why soils should be tested, how to sample soils, and where to take a soil sample for testing. More men (35.7%) than women (30.6%) and young adults (29.8%) cited that the testing centers were far away from the households. Other farmers quoted reasons such as soil testing being an expensive process (16.5%), lack of interest in soil testing (10.6%), and that the soils were already good and needed no testing (2.4%). **Figure 1** represents the reasons that farmers gave for not testing their soils.

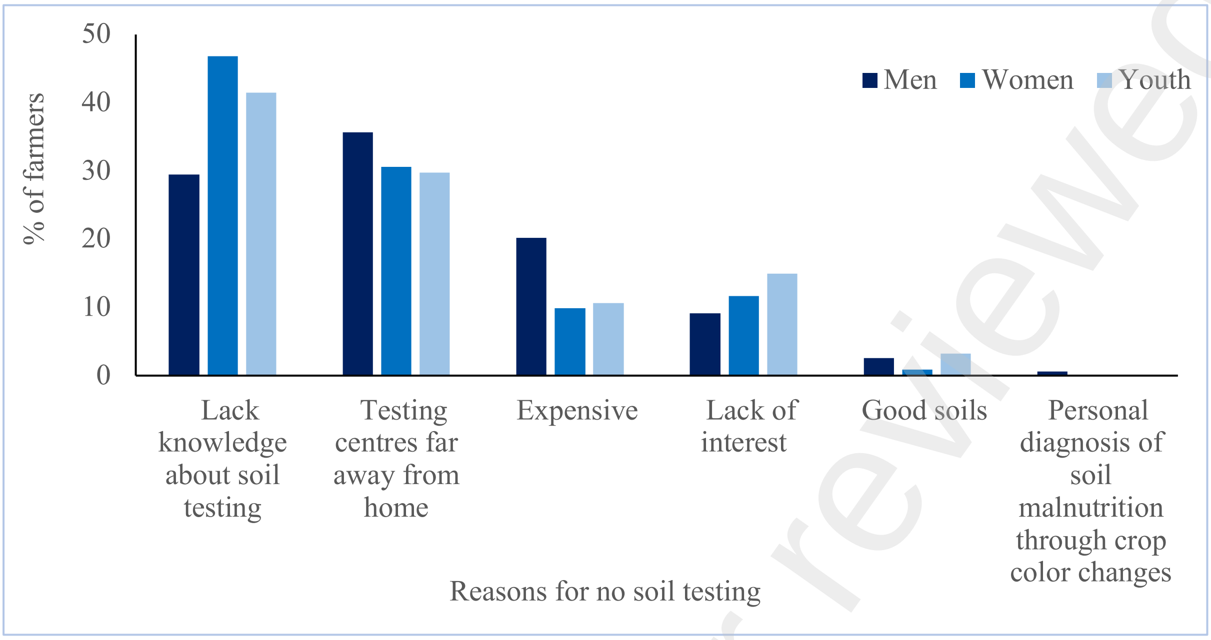

Figure 1: Reasons given by farmers surveyed for not testing their soils (n = 547)

3.5. Perceptions about a portable rapid soil testing technology

We gave to farmers a description of the workability of the potential affordable rapid testing technology for soil nutrition via a cafetiere-style filter system *in-situ* (Al Hinai et al., 2021; Nash et al., 2021; Richardson et al., 2021) and all the farmers across gender groups thought they have the capability to use it (**Table 5**). In addition, we explained to farmers that the potential rapid teting solution can cost approximately $10-12 and they perceived the technology as affordable. The majority of farmers did not find any barrier that can hinder the use of the proposed technology. A minority (3.8%) cited that the initial cost of the prototype and its complexity (1.8%) would be a barrier to its use. A vast majority (96.7%) expressed their interest in trialing the soil nutrition surveillance technology *in-situ* while a slightly lower percentage (96.3%) of farmers expressed their willingness to pay for it. Some of the few farmers who expressed their unwillingness to pay for rapid soil testing technology cited that their purchasing drive would be dependent upon the success of the technology usage among other farmers.

Table 5. Perceptions about a soil nutrition surveillance technology *in-situ*

Variable	Pooled (N=547)	Men (N=342)	Women (N=111)	Youth (N=94)	
	Freq (%)	Freq (%)	Freq (%)	Freq (%)	χ^2
Perceptions about the proposed soil nutrition surveillance technology					
If a farmer thinks he/she can use the technology	529 (96.7)	333 (97.4)	106 (95.5)	90 (95.7)	1.256
If a farmer thinks technlogy is affordable	536 (98)	339 (99.1)	104 (93.7)	93 (98.9)	13.052***
Barriers to the use of the technlogy					
None	489 (89.4)	316 (92.4)	88 (79.3)	85 (90.4)	30.534***
Initial cost	21 (3.8)	13 (3.8)	3 (2.7)	5 (5.3)	
Other	16 (2.9)	7 (2)	7 (6.3)	2 (2.1)	
Sounds complex	10 (1.8)	3 (0.9)	7 (6.3)	1 (1.1)	
No formal education	11 (2)	3 (0.9)	6 (5.4)	1 (1.1)	
Interest and willingness					
Interested in trialling technolgy	534 (96.7)	337 (98.5)	105 (94.6)	92 (97.9)	5.647*
Willing to purchase technlogy	527 (96.3)	334 (97.7)	102 (91.39)	91 (96.8)	7.987**

***, ** and * are statistical significance at 1%, 5% and 10% respectively

The study further used CVM to quantify farmers' willingness to pay for the proposed portable rapid soil testing method after the majority cited that the method can be affordable and were willing to purchase it. The findings of the uncontrolled contingent valuation method (CVM) model are presented in **Table 6**. The model positions farmers' willingness to pay (WTP) at Kes 1942.38. This is an indication that the majority of the sampled farmers accepted the initial and upper bids that bore 10% and 20% premium, respectively. The perceived need for soil testing placed farmers' WTP at 94.24% premium above the Kes 1000 that is incurred by using the existing rapid testing method.

Table 6. Estimated contingent valuation method without control variables

Variable	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
β_cons	1942.374***	166.780	11.65	0.000	1615.491	2269.258
σ_cons	544.261***	113.722	4.79	0.000	321.369	767.153
Log-likelihood	-213.389					

*** is significant at 1%

The distribution of WTP is shown in **Figure 2**, which depicts the need for soil testing among farmers. Willingness to pay goes beyond the 20% premium over the cost of existing rapid tests.

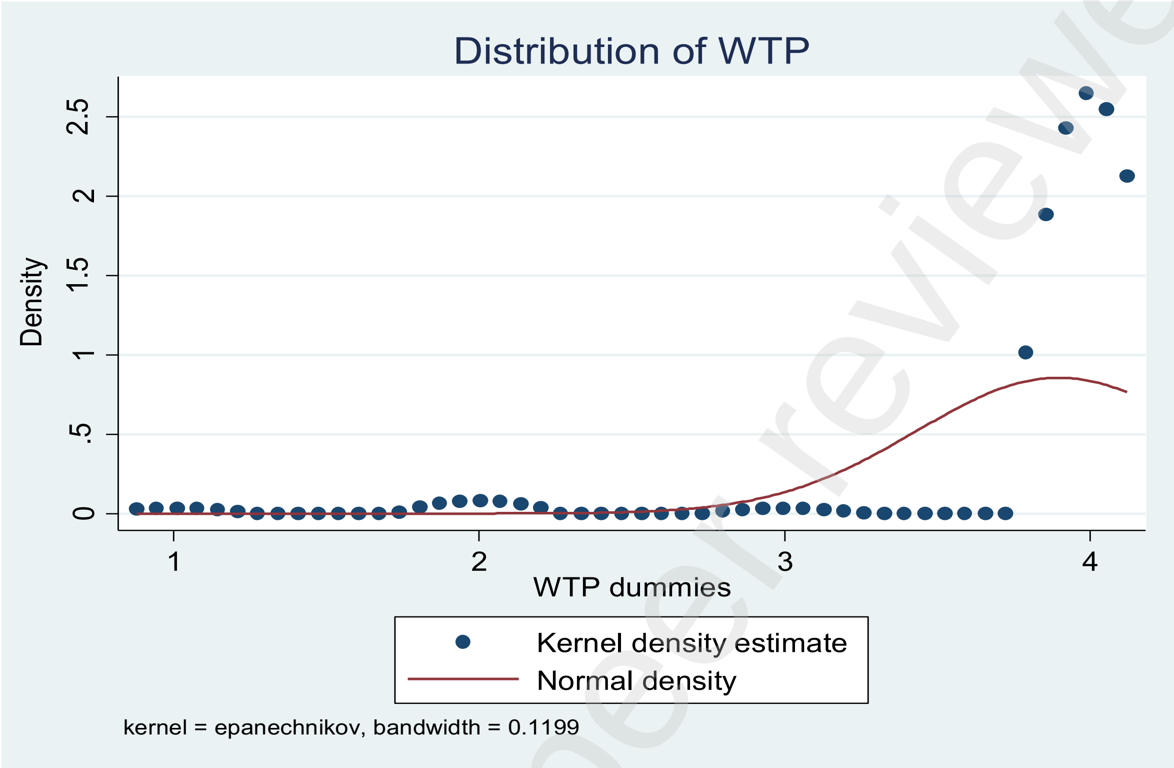

Figure 2. Distribution of willingness to pay for a soil nutrition surveillance technology *in-situ*

The overall WTP obtained from a controlled CVM model (**Table 7**) was Kes 1534.28, which is Kes 400 less than the uncontrolled WTP (see **Table 6**). After gender disaggregation, the young adult farmers had the highest WTP value of Kes 1612.53 for the new technlogy. Men had the least value of WTP at Kes 1504.83. From previous studies, young adults have been found to have a high likelihood of accepting new technologies (Kahwai et al., 2021; Omotayo et al., 2021; Shee et al., 2020; Yussif et al., 2017). Men face high dependency from other family members on other matters besides farming enterprises considering that the households that they headed had large sizes. Women on the other hand had a higher WTP than men since they are mostly fully engaged in household farming matters and consider environmental conservation more personal than men (Ahiale et al., 2019).

Table 7. Gendered estimated WTP with control variables

Gender	Variable	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
Pooled	WTP	1534.281***	210.943	7.27	0.000	1120.841	1947.721
Men	WTP	1504.833***	250.099	6.02	0.000	1014.649	1995.018
Women	WTP	1558.681***	248.056	6.28	0.000	1072.501	2044.861
Youth	WTP	1612.529***	272.532	5.92	0.000	1078.377	2146.681

*** is statistical significance at 1%; WTP stands for willingness to pay

3.5.1 Influence of control variables on WTP for the new soil testing technology using contingent valuation method

Gender was a significant determinant of WTP ($p<0.05$) in which men gender positively influenced WTP as expected in **ESI4 (Table S1)**. Male farmers in SSA are known to have more resource endowments than their female counterparts. Our findings corroborate with those of (Shee et al., 2020) who found that the WTP of female farmers is mostly compromised by their societal status in which they are less likely to own the enhancing resources such as financial capital.

Literacy proficiency influences WTP positively ($p<0.01$) the findings show that WTP increased with education levels. Literate farmers can handle smartphones by reading instructions thus as farmers get to a different education category, they are likely to appreciate the technological innovations. Positive findings on the positive influence of education level on WTP for agricultural technologies were also reported by (Verma et al., 2020), (Ahiale et al., 2019; Shee et al., 2020). The authors acknowledge that literate farmers with primary and post-primary education are mostly first to receive information about new technologies and adopt them first.

Self-employment on the farm (agribusiness) had a significant positive influence on WTP ($p<0.05$). The majority of farmers in SSA do agriculture for subsistence (Salami, Kamara, Abdul, & John, 2010). This study, however, shows that when farmers conducted the farming activities as business or employment, their WTP for the simple portable system increased. The findings support those of (Mottaleb, 2018) who found that a farmer who assumes agriculture as self-employment and the main occupation has positive significant WTP for new agricultural technologies. (Kahwai et al., 2021) however, found that a farmer involved in other employment off-farm has a higher WTP for new agricultural technology as it will help them manage both on-farm and off-farm activities efficiently.

The higher the income a farmer earned from all sources, the lower their WTP for agricultural technologies ($p<0.01$). (Ahiale et al., 2019; Yussif et al., 2017) also found a negative influence of increasing income on WTP and adopting new technology. The explanation was that the trend might be driven by the push to invest in lucrative non-farm businesses such as real estate since the markets for agricultural products vary so often. The findings contradict those of (Kahwai et al., 2021) who alluded that farmers with high income have an increased capacity to purchase new technology and becoming early adopters.

A larger household size reduced farmer's WTP for the proposed simple analytical tool for soil surveillance in situ ($p<0.01$). (Omotayo et al., 2021) found out that as the household grows bigger, the more likely it adopts the conventional agricultural practices. This might be caused by the imbalance between expenditure on consumable goods such as food and investment in new agricultural technologies. Similar findings were reported by (Yussif et al., 2017).

Willingness to pay for the soil nutrition surveillance technology *in-situ* is influenced positively by age but the influence reduced as age advanced ($p<0.01$). (Shee et al., 2020), (Kahwai et al., 2021; Omotayo et al., 2021; Yussif et al., 2017) reported similar findings. (Kahwai et al., 2021) reported that as farmers advance in age, they become more conservative regarding the acceptance of new technology. The research added that youthful farmers usually exhibit the swift acceptance of new agricultural technologies. Therefore, youthful farmers are likely to invest a large share of their investments in new agricultural technologies (Yussif et al., 2017).

Farmers who received off-farm income have lower WTP for the simple soil nutrition surveillance technology *in-situ* than their counterparts who did not receive off-farm income ($p<0.1$). Although diversification of income is expected to increase farmer's ability to acquire new technology (Ulimwengu & Sanyal, 2011), our findings corroborate those of (Yussif et al., 2017) who found a negative influence of off-farm income on WTP for new technology. As such, a farmer who engages in off-farm income-earning activities is likely to do more monetary investment off-farm than on-farm.

Longer distances to the nearest input/product market significantly lowers WTP for a soil nutrition surveillance technology *in-situ* ($p<0.01$). Households located far from the market were also previously reported by (Kahwai et al., 2021) to have a lower WTP for new technologies than those close to the market. The study alluded that households far from the nearest market are likely to suffer from non-exposure of information on agricultural technological advancements. Farmers in such areas consider investment in new technology as an extra cost besides the costs associated with access to the far located markets.

A high livestock density implies a reduction in WTP for the soil nutrition surveillance technology *in-situ* ($p<0.01$). Farmers whose inclination is livestock production have lower WTP for the soil nutrition surveillance technology *in-situ*. The livestock production enterprise sustains soil fertility through application of FYM on fodder farms (Hoffmann, 2002). Farms, therefore, remain fertile throughout the year.

In summary, men are more endowed with monetary resources than women, and thus they are willing to accept a technology that may give them convenience in soil nutrition analysis by paying a premium price. However, they are faced with much dependency to cater for the needs of the rest of the family especially in a large household. Literate farmers are more willing to accept and pay for a technology because they do not have much difficulties in reading and understanding instructions associated with a technology. It is easy for farmers who take their farming activities as agribusiness to accept the premium associated with a portable soil testing technology compared to their counterparts who farms for subsistence. There is a possibility that a farmer with high income might prioritize to invest off-farm before investing in a new on-farm technology. The larger the household the more dependency on household head and the lower the willingness to pay for a new technology. Young farmers are more ready for a convenient soil testing technology than their elder counterparts. Farmers in remote areas may suffer from low information access on technology updates, which may lower their acceptability for the technology. Farmers with more inclination to livestock production may not be so willing to pay for a new soil testing technology because they do not have soil infertility problems.

3.6 Perceptions toward democratization of soil nutrition data

Table 8 shows that almost all (99.3%) farmers did not have their soil nutrition data shared on a public platform. The few (0.7%) farmers who shared their data did it within their farmer groups. The research enquired from farmers about the person they thought was suitable to access their soil nutrition data. The main persons included agricultural extension officers (26.7%), farm owners (26%), everyone (21%), and fellow farmers (13.5%). The majority (88.1%) of the farmers perceived democratization of data as beneficial, for instance, they cited that if an intervention agency or persons had access to their soil nutrition data, they would get the relevant advice or help. In contrast, only 3.3% thought that data sharing would raise issues such as infringement of private data.

Table 8. Gendered perceptions toward democratization of soil nutrition data

Variable	Pooled (N=547)	Men (N=342)	Women (N=111)	Youth (N=94)	
	Freq (%)	Freq (%)	Freq (%)	Freq (%)	χ^2
Soil data publicly shared	4 (0.7)	3 (0.9)	1 (0.9)	0	0.837
Person to access soil nutrition data					15.669
Agricultural extension officer	146 (26.7)	85 (24.9)	31 (27.9)	30 (31.9)	
Farm owner	142 (26)	95 (27.8)	31 (27.9)	16 (17)	
Everyone	115 (21)	67 (19.6)	26 (23.4)	22 (23.4)	
Fellow farmers	74 (13.5)	44 (12.9)	15 (1.5)	15 (16)	
No one	34 (6.2)	23 (6.7)	4 (3.6)	7 (7.4)	
Academics, scientists, universities	14 (2.6)	12 (3.5)	1 (0.9)	1 (1.1)	
County government	9 (1.6)	6 (1.8)	1 (0.9)	2 (2.1)	
Family members	9 (1.6)	6 (1.8)	2 (1.8)	1 (1.1)	
Others	4 (0.8)	4 (1.2)	0	0	
Benefits/issues					
Perceived soil data sharing benefits	482 (88.1)	303 (88.6)	97 (87.4)	82 (87.2)	0.202
Perceived soil data sharing issues	18 (3.3)	12 (3.5)	4 (3.6)	2 (2.1)	0.485

4. Conclusions

Currently, soil testing among the smallholder farmers is extremely low and farmers apply fertilizers on untested soils. Some of the main reasons behind the observed low testing capacity include high costs of soil testing. A proposed prototype for soil nutrition surveillance technology *in-situ* can address the issue of portability, cost, and ease of use by farmers. Farmers are willing to pay for *in situ* measurement systems that might be a solution to the high occurrences of farmers not testing their soils in Kenya. We find that WTP values among the youth farmers and women were higher than those of men. Women and young adults have lower access to assets, TLU, and land compared to men. Policy environment and development partners should focus more on these groups to enhance their access to important factors that might enable their WTP to come true. Farmers are also willing to share their soil fertility data through democratization in cloud storage. Farmers receive less than one extension visit in a year despite them showing their need to have the agricultural extension officers access their soil nutrition data. Seemingly, farmers have confidence in extension services but the officers are not easily available. Since many farmers do not know soil nutrients and pH that affect fertility, there should be put in place policies that increase financial and transport facilitation for the extension officers to teach as many farmers as possible. This can increase farmers' urge to do soil testing and mitigate soil fertility and pH accordingly, eventually increasing agricultural productivity.

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Supplementary Materials

Gendered farmer perceptions towards soil nutrition and willingness to pay for a cafetiere-style filter system for soil testing *in-situ*: evidence from Kenya

Philip Kamau,[a] Ibrahim Ndirangu,[a] Samantha Richardson,[b] Nicole Pamme,[c*] Jesse Gitaka[a*]

[a] Directorate of Research and Development, Mount Kenya University, P.O. Box 342-01000, Thika, Kenya

[b] School of Natural Sciences, University of Hull, Cottingham Road, Hull HU6 7RX, UK

[c] Department of Materials and Environmental Chemistry, Stockholm University, SE-106 91 Stockholm, Sweden. nicole.pamme@mmk.su.se

ESI 1. Description of the study area

Gatundu south sub-county has a population of 121,693 persons from 31,472 households and covers 192.4 km^2 (Kenya National Bureau of Statistics, 2019). The sub-county receives a bimodal rainfall pattern with the first peak of long rains occurring between March to May while the second peak of short rains occurs between October to December. The precipitation in the area exceeds 2,000 mm with annual temperatures of mean 18-22°C. A mixture of deep and well-drained reddish-brown Rhodic Nitisols and Humic Nitisols soils are found in the area (National Irrigation Board, 2016). These soils support the cultivation of multiple crops including food crops (*e.g.* potatoes, beans, and maize), tropical fruits (*e.g.* avocado, oranges, and pawpaw), coffee, and tea. Also, farmers engage in livestock production as a diversified livelihood strategy.

Kandara sub-county population is 175,098 persons from 50,704 households and covers 193.6 km^2 (Kenya National Bureau of Statistics, 2019). The sub-county receives rainfall in a bimodal pattern with precipitation of above 2,600 mm. The long rains in this area start towards the end of March and hit the highest precipitation in April and begin to lower towards the end of May. The short rains kick off in October with the highest precipitation experienced in November. The annual temperatures in the Kandara sub-county are 18-21°C. The area has Humic Nitisols soils that are characterized by acidic topsoil, dark reddish-brown color, extremely deep, and a well-drained profile (Esilaba et al., 2013). Farmers engage in mixed crop-livestock production systems.

ESI 2. Questionnaire

MOUNT KENYA UNIVERSITY AND UNIVERSITY OF HULL
POINT OF NEED SIMPLE ANALYTICAL TOOLS FOR IN-SITU SURVEILLANCE OF SOIL NUTRITION IN RESOURCE-LIMITED SETTINGS SURVEY 2021

Introduction
We are currently conducting a survey with the goal of getting farmers' feedback regarding a potential ***point of need simple analytical tools for in-situ surveillance of soil nutrition in resource-limited settings***. You have been randomly selected to take part in this survey and your **VOLUNTARY** participation in this survey will be very helpful as we develop the rapid soil nutrition diagnostics tools further. Your opinion will be treated with absolute **CONFIDENTIALITY** and the analysis of your feedback will be in combination of those others.

GENERAL INFORMATION

Questionnaire number (QNUM) ____
Enumerator ____ ECODE_________
Respondent's name (optional)____
County ____
Subcounty ____
Ward ____
Village ____
Category of the respondent
1=Men [__] 2=Women [__] 3=Youth [__]
Name of the household ____
Do you usually make efforts to mitigate and address the soil situation? **mitgeffort__**
1=Yes [__]
0=No [__]

SECTION A: FARMER'S AWARENESS / KNOWLEDGE OF SOIL MALNUTRITION AND ACIDITY

A1. Do you know the **soil nutrients and pH?** **knownuts____**
1=Yes [__]
0=No [__]

If no, proceed to A3

A2. If **yes** in **A1**, please tick the items as you know them?
1=Nitrogen (N) [__]
2=Phosphorous (P) [__]
3=Potassium (K) [__]
4=Magnesium (Mg) [__]
5=Calcium (Ca) [__]
6=Sulphur (S) [__]
7=Other (specify) [__]

A3. Are you aware of soil **nutrients loss?**

1=Yes [__]
0=No [__] **awareloss___**

A4. If **yes** in **A3**, what are the possible causes of nutrients loss? **Losscaus___**

1=Soil erosion [__]
2=Underuse of fertilizers and manure [__]
3=Leaching [__]
4=High soil acidity [__]
5=Burning of the crop remains [__]
6=Continuous cropping [__]
7=Monocropping [__]
8=Other (specify) ___________________

A5. On a scale of 1-5, how would you describe the soil nutrient levels on your farm? **nutlevs___**

1=Very poor [__] 2=Poor [__] 3 =Fair [__] 4=Good [__] 5=Very good [__]

A6. How did you know **about soil nutrients, pH, and nutrients loss**? **knowlsourc_______**

1=Radio [__]
2=Newspaper [__]
3=School [__]
4=Agricultural extension service [__]
5=Seminar [__]
6= Fellow farmers
7=Other (specify) ____________

****

PART I: QUESTIONS ON HOW FARMERS MITIGATE SOIL NUTRIENTS LOSS AND PH

SECTION B: AVAILABLE SOIL PROBLEMS REMEDY EFFORTS

B1. Which method (s) do you use to mitigate and address soil nutrients loss and pH? **mitmthd___**

1=Inorganic fertilizers [__]
2=Manure [__]
3=Crop residues [__]
4=Fallowing [__]
5=Compost [__]
6=Other (specify) _____ [__]

B2. What are the **reasons** why you **mitigate soil nutrients loss** using the methods in **B1**?

1=Health concerns [__]
2=Affordable [__]
3=Advice by an extension officer [__]

4=Low financial capabilities [__]
5=The only available in the area [__]
6=Other (specify) __________ [__]

B3. How **often do you usually at least mitigate nutrients loss**? **mitgoft______**

1=Monthly [__]
2=Bi-monthly [__]
3=Quarterly [__]
4=Semi-annually [__]
5=Annually [__]
6=Bi-annually [__]
7=Other (specify)___ [__]

B4. If the answer in **B1** is inorganic fertilizer, who mainly does the **actual purchase of the fertilizer** in your household? **fertpurch______**

1=Household head [__]
2=Spouse [__]
3=Sons/daughters [__]
4=House help [__]
5=Any HH member [__]

B5. Please indicate the following **details on the inorganic fertilizers** that you have purchased in the **last two seasons (2020/2021)**

Fertilizer brand **(Code A)**	Quantity purchased	Quantity units 1=Kgs, 2=Litres	Price per unit **(KES)**	Outlet where **MAINLY** bought (***one main outlet per fertilizer***) 1=NCPB 2=Agrovet 3=Open market 4=Cooperative 5=Small traders 6=Farmer groups 7=Fertilizer company agents 8=Neighbors 9=Other(specify)___________	**Reason for choice of this outlet** 1=Reliable 2=Near to home 3=Quality products 4=Only outlet 5= Other(specify) ________	Level of trust on this outlet 0= None 1=Low 2=Moderate 3=High	Distance from home to the outlet **(KMS)**
Fert	**qtypurc**	**Units**	**price**	**Outlet**	**Choice**	**Trust**	**dist**

Code A: 1=DAP	7=SA (21:0:0)	13=Kero green	19= Other (specify) _______
2=MAP	8= DSP	14=Mijingu 1100	
3=CAN	9= TSP	15=Mavuno basal	
4=NPK	10= SSP	16=Mavuno basal	
5=ASN	11=Foliar feeds	17=I can't remember	
6=UREA	12= Magmax Lime	18=I don't know	

(ENUME: for NPK fertilizers, consider the evidence of composition of each element in the fertilizer)

B6. Does any of the above-mentioned fertilizer outlets in **B5** sell using **promotional strategies** when marketing fertilizers to farmers? **prostagy______**

1=Yes [__]
0=No [__]

B7. If yes in **B6**, which are these **strategies?**

1 = Advertisement [__]
2 = After sales service [__]
3 = Quality display [__]
4 = Special packaging [__]
5 = Special offers [__]
6 = Other (specify) _______ [__]

****

PART II: SOIL NUTRITION AND PH DIAGNOSTIC TESTS

C1. Before using any soil nutrient replenishing method, do you usually have **your soil tested for nutrient deficiency and pH**? **soiltest______**

1=Yes [__]
0=No [__]

If No, go to C5

C2. (For yes in **C1**) Please indicate the following **details on the soil diagnostics** that you have acquired in the **last 5 years**

Soil testing **organization or company** 1=KALRO 2=University of Nairobi 3=Crop Nutrition Laboratory Services Ltd (CROPNUTS) 4= Lagran Group Limited 5= Oxfarm Organic Ltd 6=JKUAT 7=Other (specify) __________	Cost of soil nutrition & pH testing (Kes)	Distance from home (Km)	Cost of public transport (Kes)	Total cost (Kes)	**Reason for choice of this outlet** 1= Reliable 2=Near to home 3= Quality products 4= Only outlet I know 5= Other (specify) ________________	Level of **trust** on soil tests from this premise 0= None 1=Low 2=Moderate 3=High

C3. As a farmer what **challenge** do you face from the soil tests by the organization or the company that performs them? **Testchal______**

0=None [__]
1=Expensive [__]
2=Takes time before the results are back [__]
3=Inadequate soil sampling skills [__]
4=Irregular testing [__]
5=Inconveniences cropping activities [__]
6=Other (specify) ________

C4. Are you **aware of any rapid soil testing** method from any company? **awaretest__**

1=Yes [__]
0=No [__]

C5. (For no in **C1**) If you **know about soil testing but do not access it,** what are **the reasons**?

1=Expensive [__]
2=My soil is highly fertile [__]
3=I have enough experience to diagnose the deficient nutrients [__]
4=I don't know anything about soil testing [__]
5=The testing org/Co is far from here [__]
6= Other (specify)________________ [__]

C6. (For no in **C1**) What **remedies** do you think should be **put in place for you to start the soil tests**? **remd_____**

1. ____
2. ____
3. ____
4. ____
5. ____

****

PART III: PERCEPTIONS AND ATTITUDES OF SIMPLE SOIL MONITORING TOOL

(ENUMERATOR: you should carefully explain the main features of power-free cafetiere-style filter system combined with a colour readout PAD and smartphone readout to the farmers, and then ask the questions that follow)

The power-free cafetiere system entails simple analytical tools for rapid on-site surveillance of soil nutrition *in-situ* in resource-limited settings. It entails the use of cafetiere for soil filtration and a **microfluidic paper-based analytical device (PAD**) for colorimetric readout and detection. A mobile app that interprets the findings of the PAD will help in collecting feasibility data for a future inventory that will help the government and farmers beyond this area. The system will help to detect soil nutrients (N & P) deficiency and pH. The Cafetiere costs around Kes 1000 while the PADs will cost you **at most Kes 100**. You will only be required to procure the cafetiere once which makes soil testing easier as you will only be procuring the PADs when you need to do the diagnostic tests. The other available rapid method will require you to pay at least Kes 1200 every time you want to have some soil tests. It has to be done by a soil scientist but the system that we are proposing for you will have you do the tests on your own. The following are the **key features of the ideal soil rapid diagnostic system**:

- Cafetiere
- A microfluidic PAD
- A mobile app

D1. We would like to capture your perceptions and attitudes about the prototype based on description above.

Question Number	Answer Options
D1.1. After listening to the above description, do you think you would use this method of soil nutrient analysis? (please explain)	1=Yes 0=No Plus, an Open Answer if any
D1.2. Is this an affordable method to analyse your soil nutrients?	1=Yes 0=No Plus, an Open Answer if any
D1.3. What are the potential barriers to using this method?	0=None 1=Initial cost 2=Sounds complex 3=I have no formal education 4=Other (specify)
D1.4. Would you be interested in trialling out this method?	1=Yes 0= No
D1.5. If yes to **D1.4**, we may be in touch in the future regarding this method using your phone numbers.	
D1.6. If no **D1.4**, why are you not interested in trialling this method?	Open Answer

D2. After the description above **would you be willing** to purchase the **power-free cafetiere system**? **willpurc________**

1=Yes [__]
0=No [__]

If yes to D2, proceed to Question D4

D3. If **No** in **D2** above, **give reasons** why you are **not willing to purchase** the power-free cafetiere system
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………

D4. **First offer:** Considering that the available rapid test will cost you at least Kes 1000 for every soil test, will you **be willing to pay** a price of **Kes 1100** for a cafetiere system that is payable once?[1] **offer1_____**

1=Yes [__]

[1] 10% premium for convenience and possible sustainability of the diagnostics

0=No [__]

D5. Second offer I: If **Yes** in **D4** above, will you be willing to pay a price of **Kes 1200** for a cafetiere system that is payable once?[2] **offer1_____**

1=Yes [__]
0=No [__]

D6. Second offer II: If **No** in **D4** above, will you be willing to pay a price of **Kes 1050** for a cafetiere system that is payable once?[3] **offer1_____**

1=Yes [__]
0=No [__]
****

PART IV: PERCEPTIONS AND ATTITUDES TOWARDS THE DEMOCARTISATION OF DATA AND PROPOSED APP

Enume: description of app: We are thinking of developing a mobile application that compiles the data of all farm soil nutrients and pH in Kenya and sub-Saharan Africa. The app will load the coordinates of the Global Positioning System (GPS) to allow more data into a soil nutrition democratized database (cloud storage). It will be able to capture and store geotagged photos of the µPADs for analysis of the colorimetric results. This will enhance future information that is essential for tracking, navigation, and preparation of maps on soil pH and nutrition-diagnosed areas for many years. The GPS data that accumulates in the cloud database will be an avenue to inform future localized government interventions. Mapping the soil pH and nutrition for several years can help the researchers to paint a picture of the possible crop yields due to reliable information regarding soil fertility.

SECTION E: Please answer the following questions regarding your data

Question	**Answer Options**
E1. Is your soil nutrient data currently shared with any other agencies? (please explain who, if your soil data is shared)	1=Yes 2=No Plus, open answer if any
E2. Is the information you share made publicly available?	2= Don't know 1=Yes 0=No
E3. Who do you think should have access to soil nutrient data? (Tick all that apply)	0=No one 1=All data should remain private to the individual farmer 2=Farm owner 3= Local farmers union groups 4= County government 5= National Government/Agricultural extension office 6= Academics, Scientists and Universities 7= Anyone / Other (please explain)

[2] 20%
[3] 5%

E4. Do you see any benefits of soil nutrient data being shared? (Please explain)	1=Yes 2=No plus, open answer if any
E5. Do you see any issues with soil nutrient data being shared? (Please explain)	1=Yes 2=No plus, open answer if any

PART V: HOUSEHOLD INFORMATION

SECTION F: CROP PRODUCTION 2020/2021

F1. Do you do irrigation in your crop production?
1=Yes
2=No

F2. Please indicate the following **details on crop production** for the past year 2020/21

Crop codes	Area (ha)	Land preparation 1=Manual 2=Oxen 3=Tractor	Seed type 1=Local recycled 2=Hybrid	Seeds (kg)	Harvest (kg)	Sold quantity (kg)	Sale price (Kes/kg)	Intercropped 0=No 1=Yes	Land tenure 0=Leased 1=Own title
crop	**croparea**	**lnprep**	**sdtyp**	**sdamt**	**hvt**	**hvtsd**	**slprc**	**intcrp**	**lntnr**

Crop codes

1=Maize	6=Sorghum	11=Pyrethrum
2=Beans	7=Millet	12=Sunflower
3=Irish potatoes	8=Tomatoes	14=Garden peas
4=Sukuma wiki	9=Carrots	15=Pigeon peas
5=Cabbages	10=Wheat	16=Other (specify)

SECTION G: ASSETS OWNED

G1. Please give the following information regarding assets owned

Asset code	Quantity	Value

Asset code
1=Housing (e.g., residentials, store, animal units etc...)
2=Farm equipment (e.g., jembe, panga, slasher, wheelbarrow etc. …)

3=Transportation mode (Motorcycle, car, donkey cart, bicycle etc.….) 4=Electronics (TVs, radios, fridge, mobile phones, solar units etc. …) 5=Kitchen equipment (cutlery, pestle and mortar etc.) 6=Powered machinery (tractor, power saw, generator, planter, sheller etc.) 7=Water reservoirs (dams, tanks, wells etc. …) 8=Animals (donkeys, cows, sheep etc. …) 9=Other (specify)

G2. Farm animals owned

Animal code	Units	Value
Animal codes; 1=Cow 2=Sheep 3=Goat 4=Chicken 5=Camel 6=Goose 7=Duck 8=Rabbit		

SECTION H: DEMOGAPHIC CHARACTERISTICS (ALL FARMERS)

H1. Respondent's **gender** **gender**__________

1=Male [__]
0=Female [__]

H2. What is the **highest level of education attained**? **educlev**________

0=No formal education [__]
1=Primary [__]
2=Secondary [__]
3=College [__]
4=University [__]

H3. What is your **employment status**? **employ**________

1=Unemployed (student) [__]
2=Unemployed (Non student) [__]
3=Informal employment [__]
4=Formal employment [__]
5=Business person/ self-employed [__]

H4. What is the **range** of your **income per month**? **Income**________

1=None (student) [__]
2=None (Non student) [__]
3=Low (Kes1-15000) [__]
4=Middle (Kes 15000-50000) [__]
5=High (> Kes 50000) [__]

H5. What is your **religion**? **religion**_________

1=Catholic [__]
2=Protestant (mainstream) [__]
3=Protestant (Pentecostal) [__]
4=SDA [__]
5=Muslim [__]
6=Other (specify) _____________

H6. How many members are in your household? **hhmems**_________

H7. Please indicate how many household members are in these age categories

< 18 years ___________
18-55 years ___________
>55 years ___________

H8. Do you earn off-farm income? **offrminc**___

1=Yes [__]
0=No [__]

H9. If yes in H8, state the amount (Kes) **offarmincamt**_________

<u>THANK YOU FOR YOUR CO-OPERATION</u>

ESI 3.

Contingent valuation model (CVM) for willingness to pay for a cafetiere-style filter system for soil nutrition surveillance *in-situ*

Regarding the cost of testing a soil sample using the only available rapid soil testing method in the study area, the first bid was Kes 1100, which bore a 10% premium price in comparison to a minimum of Kes 1000 that farmers pay for the available rapid soil testing method. If a farmer responds "yes" to the first price bid B_i, a second higher bid (Kes 1200) bearing a 20% premium price was presented B_i^u, where ($B_i^u > B_i$). If the consumer responds "no" to the first bid B_i, a second bid B_i^d (5% premium price) was presented where ($B_i^d < B_i$). Therefore, with an assumption of $WTP_i(Z_i, u_i) = Z_i'\beta + u_i$ and $u_i \sim N(0, \sigma^2)$, the four outcomes expected are;

1. "yes" to first bid and second bid (π^{yy}),

$$\pi^{yy}\ (B_i, B_i^u) = Pr\ (WTP_i > B_i, WTP_i \geq B_i^u)$$

$$= Pr\ (Z_i'\beta + u_i > B_i, Z_i'\beta + u_i \geq B_i^u)$$

where WTP_i is the true unobserved WTP for respondent *i*, B_i^u and B_i^d are the price changes randomly assigned to respondent *i*, β is a vector of coefficients to be estimated for explanatory variables in vector X. Applying the Bayes rule that states $Pr\ (A, B) = Pr(A/B) * Pr\ (B)$, we develop the following equation (Lopez-Feldman, 2012);

$$\pi^{yy}\ (B_i, B_i^u) = Pr(Z_i'\beta + u_i > B_i | Z_i'\beta + u_i \geq B_i^u) * (Z_i'\beta + u_i \geq B_i^u)$$

By description, $B_i^u > B_i$ while $Pr(Z_i'\beta + u_i > B_i | Z_i'\beta + u_i \geq B_i^u) * (Z_i'\beta + u_i \geq B_i^u) = 1$, which means that;

$$\pi^{yy}\ (B_i, B_i^u) = Pr\ (u_i \geq B_i^u - Z_i'\beta)$$

$$= 1 - \Phi\left(\frac{B_i^u - Z_i'\beta}{\sigma}\right)$$

Symmetrically, assuming normal distribution we end up with;

$$\pi^{yy}\ (B_i, B_i^u) = \Phi\left(Z_i'\frac{\beta}{\sigma} - \frac{B_i^u}{\sigma}\right) \tag{1}$$

2. "yes" followed by "no" (π^{yn}),

$$\pi^{yn}(B_i, B_i^u) = Pr\ (B_i \leq WTP_i < B_i^u)$$

$$= Pr\ (B_i \leq Z_i'\beta + u_i < B_i^u)$$

$$= Pr\left(\frac{B_i - Z_i'\beta}{\sigma} \leq \frac{u_i}{\sigma} < \frac{B_i^u - Z_i'\beta}{\sigma}\right)$$

$$= \Phi\left(\frac{B_i^u - Z_i'\beta}{\sigma}\right) - \Phi\left(\frac{B_i - Z_i'\beta}{\sigma}\right)$$

Following the rule that $Pr\ (a \leq X < B) = F(b) - F(a)$ and normal distribution symmetry we derive equation 2 for the responses following a "yes" and "no".

$$\pi^{yn}(B_i, B_i^u) = \Phi\left(Z_i'\frac{\beta}{\sigma} - \frac{B_i}{\sigma}\right) - \Phi\left(Z_i'\frac{\beta}{\sigma} - \frac{B_i^u}{\sigma}\right) \quad (2)$$

3. "no" followed by "yes" (π^{ny}),

$$\pi^{ny}(B_i, B_i^d) = Pr\ (B_i^d \leq WTP_i < B_i)$$

$$= Pr\ (B_i^d \leq Z_i'\beta + u_i < B_i)$$

$$= Pr\left(\frac{B_i^d - Z_i'\beta}{\sigma} \leq \frac{u_i}{\sigma} < \frac{B_i - Z_i'\beta}{\sigma}\right)$$

$$= \Phi\left(\frac{B_i - Z_i'\beta}{\sigma}\right) - \Phi\left(\frac{B_i^d - Z_i'\beta}{\sigma}\right)$$

Following the normal distribution symmetry;

$$\pi^{ny}(B_i, B_i^d) = \Phi\left(Z_i'\frac{\beta}{\sigma} - \frac{B_i^d}{\sigma}\right) - \Phi\left(Z_i'\frac{\beta}{\sigma} - \frac{B_i}{\sigma}\right) \quad (3)$$

4. "no" for both responses (π^{nn}),

$$\pi^{nn}(B_i, B_i^d) = Pr\ (WTP_i < B_i, WTP_i \leq B_i^d)$$

$$= Pr\ (Z_i'\beta + u_i < B_i, Z_i'\beta + u_i \leq B_i^d)$$

$$= Pr\ (Z_i'\beta + u_i < B_i^d)$$

$$= \Phi\left(\frac{B_i^d - Z_i'\beta}{\sigma}\right)$$

Following the normal distribution symmetry;

$$\pi^{nn}(B_i, B_i^d) = 1 - \Phi\left(Z_i'\frac{\beta}{\sigma} - \frac{B_i^d}{\sigma}\right) \quad (4)$$

There is no preexistent model such as Probit or Logit that can estimate WTP using equations 1 to 4 unlike if we used a single bounded CVM. We used maximum likelihood estimation (MLE) to directly acquire the value of β and σ following the novel Lopez-Feldman likelihood function. To obtain the relevant parameters, we maximized the following function;

$$\sum_{i=1}^{N}\left[\pi^{yy}\ln\left(\Phi\left(Z_i'\frac{\beta}{\sigma}-\frac{B_i^u}{\sigma}\right)\right)+\pi^{yn}\ln\left(\Phi\left(Z_i'\frac{\beta}{\sigma}-\frac{B_i}{\sigma}\right)-\Phi\left(Z_i'\frac{\beta}{\sigma}-\frac{B_i^u}{\sigma}\right)\right)\right.$$
$$+\pi^{ny}\ln\left(\Phi\left(Z_i'\frac{\beta}{\sigma}-\frac{B_i^d}{\sigma}\right)-\Phi\left(Z_i'\frac{\beta}{\sigma}-\frac{B_i}{\sigma}\right)\right)$$
$$\left.+\pi^{nn}\ln\left(1-\Phi\left(Z_i'\frac{\beta}{\sigma}-\frac{B_i^d}{\sigma}\right)\right)\right] \tag{5}$$

Where a farmer enters once in each of the relevant cases π^{yy}, π^{yn}, π^{ny}, and π^{nn} though 1 or 0 dummy in the logarithmic likelihood function. Φ represents the standard normal cumulative distribution function. The MLE directly evaluates $\widehat{\beta}$ and $\hat{\sigma}$, mean WTP for a simple affordable portable soil testing tool is the constant of the likelihood function for an equation with no control variables. Estimating WTP in an equation using control variables involves creating scalar values for each explanatory variable. Supplementary Table 2 shows the variables used in the measurement of WTP in CVM, their description, and expected signs.

ESI 4. Variables used in contingent valuation model (CVM)

Table S1. Variables used in contingent valuation method model

Variable	Description and measurement of variable	A priori sign
Dependent variables		
WTP	Willingness to pay for the proposed system in Kenya Shillings (Kes): • 1=yy if yes to first and second bid; 0=otherwise • 1=yn if yes to first bid and no to second bid; 0=otherwise • 1=ny if no to first bid and yes to second bid; 0=otherwise • 1=nn if no to first and second bid; 0=otherwise	
Independent variables		
Gender	Gender of the HHH is a binary variable: 1=Male; 0=Female	+
Education	Education of the HHH is a dummy variable: 2= Post-primary education; 1=Primary education; 0=No formal education	+/-
Employment	HHH employment type is a dummy: 3=Formal employment; 2=Informal employment; 1=Unemployed	+
Income	Monthly income of the HHH is a dummy: 3= Above Kes 50000; 2=Kes 15000 – 5000; 1=Kes 0 – 15000	+
Off-farm income	Off-farm income is a binary variable: 1=HHH received off-farm income; 0=otherwise	+
Household size	Household size is a continuous number	+/-
Group membership	Membership to an organized association/group is a binary variable: 1=HHH belonged to a group; 0=otherwise	+
Land tenure	Land tenure is a binary variable: 3=Owned titled and leased; 2=Owned title; 0=Leased	+
Credit access	Access to credit is a binary variable: 1=HHH received credit for agricultural use; 0=otherwise	+
Distance to market	Distance to the nearest input/product market measured in kilometers	-
Extension contacts	Number of times an agricultural extension officer visited the farm from April 2020 to February 2021	+
TLU	Tropical livestock units measured as an index: cow (0.7); goat/sheep (0.1); chicken/fish (0.01); camel (1.1); goose/turkey/duck (0.03); rabbits (0.02); pig (0.2)	+/-
Gender category	Gender category which the HHH belong is a dummy variable: 3=Youth; 2=Women; 1=Men	+/-
Area under crops	Area under crop production measured in acres	+/-
Irrigation	If the household does crop production under irrigation: 1=A household does irrigation; 0=otherwise	+

Note: The measurements of TLU were adopted from Jahnke *et al*. (1988) and Nyariki & Amwata (2019)

ESI 5. Multicollinearity diagnosis for contingent valuation method (CVM) model

Table S2. Variance inflation factor (VIF)

Variable	VIF	1/VIF
Own land titles	9.77	0.102318
Own land titles and lease	9.53	0.104879
Primary education	6.95	0.143820
Post primary education	6.86	0.145821
TLU	4.34	0.230450
Credit	3.83	0.260759
Self employed	3.79	0.264000
Age (36-55 years)	3.34	0.299667
Formal employment	3.28	0.305083
Age (18-35 years)	3.12	0.320514
Distance to market	3.01	0.332000
Extension education	2.6	0.384053
Irrigation	2.39	0.418805
Off-farm income	1.69	0.590138
Group membership	1.64	0.611260
Household size	1.6	0.623101
Middle income (Kes 15000-50000)	1.39	0.722016
Acres under crop	1.31	0.761464
High income (> Kes 50000)	1.3	0.771306
Women	1.23	0.814616
Youth	1.14	0.874000
Sex	1.1	0.912004
Mean VIF	3.42	

ESI 6. Findings

Table S3. Gendered descriptive statistics for farmer and farm characteristics

Variable	Pooled (N=547)	Men (N=342)	Women (N=111)	Youth (N=94)	
	Freq (%)	Freq (%)	Freq (%)	Freq (%)	χ^2
Education					
No formal education	31 (5.7)	14 (4.1)	16 (14.4)	1 (1.1)	61.552***
Primary	254 (46.4)	166 (48.5)	65 (58.6)	23 (24.5)	
Secondary	189 (34.6)	115 (33.6)	26 (23.4)	48 (51.1)	
College	61 (11.2)	40 (11.7)	4 (3.6)	17 (18.1)	
University	12 (2.2)	7 (2)	0	5 (5.3)	
Employment					
Student	11 (2)	3 (0.9)	3 (2.7)	5 (5.3)	15.234**
Self employed	518 (94.7)	329 (96.2)	107 (96.4)	82 (87.2)	
Formal employment	18 (3.3)	10 (2.9)	1 (0.9)	7 (7.4)	
Income					
None (student)	2 (0.4)	0	0	2 (2.1)	27.106***
None (Non student)	2 (0.4)	2 (0.6)			
Low (Kes1-15000)	449 (82.1)	265 (77.5)	103 (92.8)	81 (86.2)	
Middle (Kes 15000-50000)	84 (15.4)	66 (19.3)	7 (6.3)	11 (11.7)	
High (> Kes 50000)	10 (1.8)	9 (2.6)	1 (0.9)		
Age					
18-35 years	94 (17.2)	0	0	94 (100)	547.765***
36-55 years	223 (40.8)	172 (50.3)	51 (45.9)		
> 55 years	230 (42)	170 (49.7)	60 (54.1)		
Off farm income	157 (28.7)	111 (32.5)	9 (8.1)	37 (39.4)	30.579***
Group membership	406 (74.2)	250 (73.1)	88 (79.3)	68 (72.3)	1.883
Credit	227 (41.5)	148 (43.3)	58 (52.3)	21 (22.3)	19.943***
Land tenure					
Leased	6 (1.1)	3 (0.9)	1 (0.9)	2 (2.1)	28.449***
Own title	505 (92.3)	321 (93.9)	109 (98.2)	75 (79.8)	
Both	36 (6.6)	18 (5.3)	1 (0.9)	17 (18.1)	
Irrigation	223 (40.8)	143 (41.8)	35 (31.5)	45 (47.9)	6.041**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	F-value
Assets	466764.17 (437417.72)	505456.14 (461286.93)	405135.14 (385763.97)	398765.96 (390352.15)	3.610 **
Extension education	0.68 (1.1)	0.74 (1.21)	0.76(1.34)	0.39 (0.90)	3.389**
Market distance	2.41 (3.66)	2.39 (3.5)	2.5 (3.97)	2.37 (3.86)	0.43
Crop area	1.12 (0.98)	1.2 (1.06)	1.12 (0.95)	0.81 (0.61)	5.607***
TLU	0.77 (0.5)	0.81 (0.53)	0.75 (0.47)	0.69 (0.46)	2.159
HH size	3.82 (1.66)	4.1 (1.41)	3.96 (1.68)	3.15 (1.66)	11.808***

*** and ** are statistical significance at 1% and 5% respectively; TLU represents Tropical Livestock Units; HH represents household; SD=standard deviation

Table S4. Influence of control variables on WTP for the new soil testing technology using contingent valuation method

Variable	Coef.	Std. Err.	z	P>|z|
Gender	83.085**	38.918	2.13	0.033
Education				
Primary education	151.852***	44.589	3.59	0.000
Post primary education	204.140***	56.837	3.59	0.000
Employment				
Self-employment	174.327**	74.37	2.34	0.019
Formal employment	43.214	80.51	0.54	0.591
Income				
Middle (Kes 15000-50000)	-47.461	54.702	-0.87	0.386
High (> Kes 50000)	-256.641***	87.795	-2.92	0.003
Household size	-24.243***	9.12	-2.66	0.008
Age				
36-55 years	233.662***	71.979	3.25	0.001
> 55 years	134.137***	47.801	2.81	0.005
Off-farm income	-73.232*	42.667	-1.69	0.088
Group membership	1.546	43.959	0.04	0.972
Land tenure				
Own title	1041.024	34564.52	0.03	0.976
Title + lease	869.056	34564.37	0.03	0.980
Credit access	48.24	89.538	0.54	0.590
Distance to market	-28.649***	10.695	-2.68	0.007
Extension contacts	-0.762	11.265	-0.307	0.946
TLU	-219.116***	59.846	-3.66	0.000
Gender category				
Women	5.616	59.88	0.09	0.925
Youth	64.554	78.619	0.82	0.412
Area under crops	0.725	9.171	0.08	0.937
Irrigation	34.618	73.538	0.47	0.638
Model summary				
Log-likelihood	-67.162			
Wald χ^2 (23)	40.84			
Prob > χ^2	0.008***			
No. of observations	547			
First-Bid Variable: bid1				
Second-Bid Variable: bid2				
First-Response Dummy Variable: answer1				
Second-Response Dummy Variable: answer2				

***, ** and * are statistical significance at 1%, 5% and 10% respectively