Soil fertility status in relation to farmers' practices under maize based systems in KCEP sites Western Region of Kenya: An extension tool for yield gap analysis

Abstract

A study was carried out to examine the soil fertility status in relation to the current blanket fertilizer recommendations and farmers' practices across the four wards, namely: Motosiet, Keiyo, Cherangani and Kwanza, TransNzoia County. The baseline fertility status was assessed in terms of soil productivity index with a view of analyzing the levels of nutrients and yield gaps as well as the relevance of the envisaged technologies to the identified constraints. Five soil mapping units were identified, using the standard soil survey procedures. The results showed that highest productivity index was in unit BU1, followed by UUr2, UUr4 and RUrb with values of 40.5, 29.4, 25.0, 16.0 and 8.9% respectively. The current fertilizer recommendations did not consider the variations in nutrient levels in different Wards. Keiyo Ward had the highest level of nitrogen, being 125.82, followed by Motosiet, Cherangani and Kwanza with values of 99.92, 97.12, and 81.12 kg/ha respectively. Phosphorous level was highest in Kwanza (136.41 kg/ha), followed by Cherangani (106.82 kg/ha) and Keiyo Ward (76.08 kg/ha). The lowest level was recorded in Motosiet with the value of 72.56 kg/ha. Potassium was found to be adequate in all the four Wards with values ranging between 347.67 and 410.34 kg/ha. The maximum maize production recorded in the project sites was 9,000 kg/ha, with a yield gap of 1,000 kg/ha. This was achieved through application of 100 and 50 kg/ha of DAP and CAN respectively. This was followed by 6,750 kg/ha obtained through application of 50 kg/ha of DAP and CAN. The yields from the rest of the sites ranged between 1,800 and 4,500 kg/ha with yield gaps varying from 3,250 to 8,650 kg/ha. Motosiet Ward had the highest maize yield, followed closely by Cherangani. The lowest yields were obtained in Keiyo, followed by Kwanza Ward despite the relatively high macro-nutrient levels in the two Wards. This was attributed to lower soil quality caused by the increased degradation, resulting into unfavourable soil conditions that constrained the utility of the agricultural inputs (fertilizer and rainwater). Therefore, it is strongly recommended that the envisaged climate smart technologies be geared towards enhancement of nutrient and water use efficiency through improved soil structure and tilth.

Key words: Productivity index, soil-related constraints and yield gaps

1 Introduction

1.1 The study background

Most fertilizer recommendations passed to farmers through agricultural extension in Kenya were formulated many years ago and disregarded the effects of variations in soil properties and climate change. As a result, several recommendations have become obsolete. Assessment of soil fertility and potential for a specified land use system attempts to answer the question on how the land is currently used and managed as well as the impact of the farmers' practices on soil fertility and crop yield. Addressing such question is an important component of the biophysical characterization and fertility mapping carried out for Kenya Cereal Enhancement Programme (KCEP) in Western region of Kenya (Kamoni et al. (2016).

To graduate farmers from subsistence farming and food insecurity to market-oriented farming, KCEP is addressing the key soil-related constraints to crop production by promoting good agricultural practices. Identification of good agricultural practices necessitates the establishment of the baseline soil fertility status to be used as a basis of evaluating the impacts of the change from the current practices to envisaged interventions on soil productivity. According to Driessen and Konijn (1992), assessment of baseline soil productivity usually involves integrated analysis of biophysical and socio-economic data collected through land use system analysis. In its simplest form, a land use system is composed of one land utilization type practised on one land unit. The sufficiency of the land unit properties is determined by measuring and matching the values of the selected land and soil quality indicators with the values for optimum production of the specific land use on the defined land unit. In assessing the potentials and limitations of land for a given land use system, distinction is made between land quality and soil quality. Land quality is defined as the condition, state or health of the land in relation to crop requirement, while soil quality is the capacity of a specific soil type to function within natural or managed ecosystem boundaries to sustain plant and animal production, maintain or enhance water quality, and support human health and habitation (Doran and Parkin, 1994). Although soil survey and fertility mapping are based on the soil natural boundaries, ecosystem boundaries are also considered when the impacts of land use becomes significant in reducing, sustaining, or enhancing water quality and availability through changes in soil depth. Driessen and Konijn (1992) showed that soil depth was one of the single land characteristics that was so positively correlated to crop production that separation of the same soils into different units, based on soil depth would show different levels of biophysical soil potentials and ecosystem functions.

1.2 Soil biophysical potential and its management implications

The biophysical production potential of any production system is realized when nutrient supply, plant protection and harvesting methods are optimized and the crop yield is limited only by sunshine, temperature and water. It is a fully optimized production situation, and is normally much greater than the production realized under ordinary farming circumstances. The yield gap between the biophysical production potential and the observed actual production from the farmers' fields results from the compounded effects of all the limitations that confront the real world farmer, that are supposed to be corrected by the envisaged intervention strategies (Driessen, 1997). If all the correctable limitations are eliminated, a system's biophysical performance would only be limited by the amount incoming solar energy, temperature and photosynthetic properties of the crop concerned. In glasshouses, even light and temperature can be optimized and production becomes limited only by the properties of the crop, since water supply can also be optimized. This explains why in Dutch glasshouses, tomato production reaches an incredible 500 tons/ha/year. In this context, an assessment of soil, environmental conditions, farmers' practices and crop yields prior to the identification of the appropriate intervention strategies, is a noble task, because the yield gap established for the specific land use system is an indicator of the magnitude of the management inputs required through the prescribed intervention, following the experimental research. In this case, the use of external inputs, principally fertilizers and lime, together with the use of improved crop varieties may sustain high crop yields if they are sufficiently tailored to specific land use system with known soil-related constraints and management requirements (Muya et al., 2015). Against this background, the objectives of the study were:

1. To examine the current blanket fertilizer recommendations across major soil types in different wards, the expected crop yields, farmers’ practices and yield gaps.
2. To assess the baseline fertility status in terms of soil productivity.
3. To analyze levels of nutrients in the soils in the identified soil mapping units as a basis of recommending appropriate fertilizer blends.
4. To analyze the relevance of the envisaged technologies to the identified soil-related constraints and predict their impacts on agricultural productivity

2 Materials and methods

2.1 The study area

2.1.1 Location

The study area lies within the four Wards of Trans Nzoia County, between latitudes 34^{o} 30” E and 35^{o} 30” E and longitudes 1^{o} 30”N and 1^{o} 45”N. Fourty four farmers’ fields were selected, each measuring 0.4ha, being distributed within the four Wards, namely: Motosiet, Cherangany, Kwanza and Keiyo.

2.1.2 Climatic aspects of the area, effective rains and consumptive water use

The most important climatic characteristics presented are temperatures and rainfall due to their direct influence on plant growth. The optimum temperature range for most crops is 10 to 30^{o}C, which falls within the range of the values obtained from the study sites (Table 1). Another important aspect of climate which is of the interest for study is effective rainfall. The effective rain is the fraction of rain water that infiltrates into the soil and stored within the rootzone to be consumed by the plants. It is a reflection of the interactions between climate, soil, topographical characteristics and management (e.g. tillage and terraces). The project area, being highly compact, is bound to generate relatively high volume run-off, hence low effective rain. Therefore, water deficits occur mainly between January and April when water losses through run-off are at its peak level. The negative run-off, occurring in November, is an indication of accumulation of water from other ecosystems, which needs to be intercepted through construction of appropriate tillage or other water conservation structures. Increased rates of run-off due to high soil compaction and the attendant loss of nutrient bases is one of the explanations of the increasing soil acidity and nutrient deficiency in the area. Therefore, this is one of the key soil physical and fertility constraints requiring improvement (Muya *et al.,* 2015).

Table 1: Climatic characteristics

Climatic attributes	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Totals**
Maximum temperature ^{o}C	28	29	27	26	26	26	26	26	27	27	27	27	
Minimum temperature ^{o}C	14	14	15	15	15	14	14	13	14	14	14	14	
Reference evapotranspiration (mm/day)	3.2	4.6	5.2	6.1	6.4	6.6	6.5	6.1	5.1	5.0	4.4	4.3	
Rainfall mm	74	110	166	312	250	155	224	178	161	144	144	85	1859
Maize water requirements (mm)	69	132	219	174	Fallow	Fallow	Fallow	93	123	150	`150	120	1080
Run-off (mm)	5	22	33	52	0	0	0	0	36	33	-14	20	187

Source: Muya et al. (2015)

2.1.3 The geomorphic characteristics

The geomorphic characteristics of the study were applied in developing soil mapping codes to facilitate the analysis of soil fertility and productivity. These characteristics were described by the regional Physiography that consisted of volcanic footridges, denoted by the symbol R, uplands, denoted by the symbol U, Kitale plain (P) and bottomlands (B). The geology of the area was characterized by the Pre-Cambrian Basement System Rocks, comprising quartzite and schist derived from argillaous sediments, which have been transformed by metamorphosis into quartz and feldspar-rich rocks with much biotite gneiss (N). Most of the soils have developed on the lower level uplands (U) from undifferentiated gneiss, denoted by the symbol U, and volcanic footridges (R). Based on these characteristics, the soil mapping units were coded as: RUrb, RUd, UUr1, UUr2, UUr3 and UUr4, explained as follows: RUrb consisted of soils developed from volcanic footridges (R), on Undifferentiated Basement System Rocks (U) with reddish brown soils (rb); RUd: soils developed from volcanic footridges (R) on Undifferentiated Basement System Rocks (U) with dark grayish brown soils (d). Similarly, UUr1, UUr2, UUr3 and UUr4 were soils developed from the uplands (U) on Undifferentiated Basement System Rocks with red soils (r). These soil mapping units combined with georeferencing of the sampling points from the farmers' field were applied in interpreting the results of laboratory analysis of the soil samples collected from the field.

2.2 Field methods

In each of the 44 farmers' fields, auger observation and soil sampling were carried out and georeferenced. At each sampling points, the soil mapping unit and its characteristics were recorded along with the farmers' practices. The soil samples were collected for the evaluation of soil fertility and productivity. Farmers were interviewed on the current management practices on each field sampled to establish the types and quantity of fertilizer applied and the corresponding maize yield.

2.3 Laboratory methods

The soils were oven dried at 40^0C, milled and passed through a 2mm sieve for analysis of available macro and micro nutrients following the methods of Hinga*et al*. (1980). The following available nutrient elements were analysed: N, P, K, Ca, Mg, Mn, Fe, Zn, Cu, total nitrogen and exchangeable acidity where the pH of the soil was ≤ 5.5. In soils with pH > 7.0 electrical conductivity was determined for the evaluation of soil salinity (salts). The available nutrient elements P, K, Ca, Mg and Mn were extracted using Mehlich Double Acid Method of 0.1 N HCl and 0.025 N H_2SO_4 in a 1:5 soil: volume ratio (w/v) mixture. Ca and K were determined with a flame photometer and P, Mg and Mn were determined calorimetrically. The extraction of phosphorus (P-Olsen) in soils with a pH > 7.0 was in accordance to the method of Hinga*et al*. (1980) and was determined calorimetrically.

The total organic carbon (C) was determined calorimetrically where all organic C in the soil sample was oxidized by acidified dichromate at 150^0Cfor 30 minutes to ensure complete oxidation (Anderson and Ingram, 1993).Barium chloride was added to the cooled digest, mixed thoroughly and the digest allowed to stand overnight. The C concentration was read on the spectrophotometer.

Total nitrogen was determined using macro-kjeldahl digestion method where organic nitrogen in presence of H_2SO_4, potassium sulphate (K_2SO_4), and copper sulphate ($CuSO_4$) catalyst, amino nitrogen of many organic materials is converted to ammonium. Free ammonia is also converted to ammonium. After addition of base, the ammonia is distilled from alkaline medium and absorbed in boric acid. The ammonia is determined by titration with a standard mineral acid (dilute H_2SO_4). (Hinga et.al 1980; Page et.al 1982)

Other analyses conducted were on soil pH and available trace elements. The soil pH was determined in a ratio of 1:1 and 1:2.5 soil: water (w/v) suspension and electrical conductivity using pH meter and EC-metre respectively. . The available trace elements (Fe, Zn & Cu) were extracted with 0.1M HCl in a 1:10 soil: volume ratio (w/v) and determined with Atomic Absorption Spectrophotometer (AAS).

Soil Texture was determined using the hydrometer method.

Exchangeable cations were determined with a flame photometer after successive leaching of the samples with 1N ammonium acetate at pH 7.0. Cation exchange capacity was determined after successive leaching with alcohol (95%), sodium acetate (pH 8.2) and 1N ammonium acetate (pH 7.0). The CEC was determined by measuring the Na concentration in the last leachate with a flame photometer. The analysis of total organic carbon for estimation of soil organic matter content followed the method detailed in Anderson et al. (1993). Derived parameters included exchangeable percentage (ESP) and cation exchange capacity contributed by clay (CEC-clay).

2.4 Land evaluation method

For the assessment of biophysical production potentials of the farmers' fields, indexing of soil quality and soil productivity was done using semi-quantitative land evaluation methods (Driessen and Konijn, 1992; Neill, 1979; Nyandat and Muchena, 1987), where ranges of numerical values of the selected soil quality indicators were rated and assigned fractions in percentage, being guided by the critical limits of the indicators. The critical limit of an indicator is defined as the numerical value of the soil property where crop yield is 80% of the maximum yield (Aune and Lal, 1997).

Productivity index (PI) was determined using parametric methods of land suitability assessment provided (Driessen and Konijn (1992). This involved assigning ranges of numerical values and percentage fractions to each soil property selected as key soil quality indicators and ranking for maize, beans and sorghum (Table 2) and combining all the single factor valuations in one mathematical equation that produces a numerical expression of the system performance or a relative index of performance (compounding) as follows:

$$PI=(SQ1/100) \text{ X } (SQ2/100) \text{ X } (SQ3/100) \text{ X } (SQn/100)$$

Where:

PI=Productivity index in % and SQ1, SQ2, SQ3, SQn are percentage ratings of soil quality indicator number 1, 2, and number n. The numerical values of the measured soil quality attributes were obtained from the crop response functions.

Table 2: Relationships between relative crop yield (Y) and soil properties

Crop	**Soil properties**	**Equation**	**r^2**	**Critical limit**
Maize	Soil pH	$Y=1-250\ e^{-(1.43pH)}$	0.42	5.0
Beans		$Y=-6.41+2.42pH-0.97(pH)^2$	0.68	5.1
Maize	Soil organic carbon (SOC)	$Y=0.31+0.56SOC\%-0.11SOC\%$	0.37	1.08
Maize	Phosphorous	$Y=1-0.95e^{-(0.20p)}$	0.88	7.6
Beans		$Y=1-1.03e-^{(0.15p)}$	0.78	10.6
Maize	Potassium	$Y=1-0.79e^{-(1.66K)}$	0.43	0.83
Beans		$Y=1-2.11e^{-(3.32k)}$		

Source: Aune and lal (1997)

2.5 Statistical method

Analysis of productivity indices of different fields was done using SPSS Statistical Computer Software Version 15.0 in which analysis of variance were carried out. The means were compared using ANOVA in Genstat Version 9.0.

3 Results and discussion

3.1 Baseline soil fertility status and the current recommended practices

The Establishment of baseline fertility status of the project area starts with the examination of the farms and all the operations that affect nutrient availability and application (Muya *et al.*, 2015). According to Natural Resources Conservation Services (2003), baseline analysis of the recommended practices on the ground forms the basis of deciding on the appropriate nutrient management strategies, following soil sampling and laboratory determinations. The current recommendations for the farmers in the project area are presented in Table 2, where the fertilizers used for the main crops are: urea, calcium ammonium nitrate (CAN), Diammonium phosphate (DAP) and potassium chloride (KCL). These recommendations did not consider the variations in soil fertility status resulting from the differential interactions between the soil forming factors such as Physiography, parent materials, slopes and land cover in different wards (Table 3). The predicted yield of maize, following the application of the recommended types and rates of the fertilizers was 3,300 kg/ha. This was based on the assumption that there would be adequate rainfall and efficient supply of nitrogen from the recommended quantity of urea. The predicted yield is much lower than the biophysical production potential calculated for the area when all the correctable soil-related constraints are eliminated. The omission of CAN in the recommendation package and its substation by urea may not be appropriate for the project area which is undergoing severe chemical degradation through increased acidification. The pH of most soils being less than 5.0 may decrease soil pH further through the use of acid fertilizers including urea. However, the recommendations based on the latest soil investigation and analysis results as well as the on-going research are likely to a positive impact on crop performance.

Table 3: Blanket recommended rates of fertilizers

Crop	**Application rate (kg/ha)**			
	Urea	**CAN**	**DAP**	**KCL**
Maize	50	0	100	0
Irish potatoes	35	0	0	0
Beans	35	0	30	0
Wheat	150	0	75	0

3.2 The influence of soil physical parameters on soil fertility and productivity

The baseline soil fertility status in a given area is influenced by the soil physical parameters normally used in delineating the soil mapping units. Since these parameters are subject to change, depending on the soil forming factors and degree of land degradation, they are applied in the assessment of soil fertility status through geospatial techniques (Mohamed *et al.*, 2015). The soil parameters used in describing the soil mapping units in study are presented in Table 3. The variations in these parameters between different soil mapping units accounted for the differences in nutrient levels in different wards. The undesirable soil physical attributes such as extremely compact surface and sub-surface soils, high erosion susceptibility and severely degraded areas are evidences of low soil productivity, measured by the generally low productivity index (PI), being less than the threshold of 50%. Soil compaction is a form of physical degradation resulting into densification and distortion of the soil structure, thereby adversely affecting the soil processes responsible for maintaining soil fertility (Muya *et al.*, 2015). These processes were found to be taking place at different rates in various agro-ecosystems, hence the occurrence of different soil mapping units with varying levels of macro-nutrients and productivity indices (PI).

High degree of physical degradation was also indicated by high bulk density which was found to be far much higher than the threshold value of 1,100 kg/m^3 (Driessen and Konjin, 1992). The highest level of bulk density was recorded in unit RUd, measuring 1,600 kg/m^3. This corresponded with the highest rate of land degradation in terms of severe soil erosion, with topsoils removed, thereby reducing available soil moisture holding capacity considerably. In addition, the exposed sub-surface soils were found to be, not only dense and slowly permeable, but also causing obstructed root growth.

The soil fertility status was found to be generally low, with levels of nitrogen being lower than the critical limit of 0.2 for all the soil mapping units. The soil organic carbon (SOC) was also found to be lower than the critical limit of 2.0% in all the mapping units except BU1. Phosphorous was found to be adequate in all the soil mapping units except unit UUr1, where it was less than the critical limit of 20 ppm. Potassium level was found to be less than the critical limit of 0.84 in all the soil mapping units (Table 4). In general, the research area was found to have low soil fertility status, which related with low soil productivity, with productivity indices of all the soil mapping units being less than 50%. This was due to undesirable soil physical conditions resulting from the severe physical land degradation processes. Therefore, the first step to improve soil fertility of the project area is to address the land degradation issues and their negative impacts on soil depth and soil moisture regimes. Priority for intervention to be guided by the productivity index, the highest level being found it unit BU1 (40.5%), followed by UUr1, UUr2, UUr4 and RUrb with values of 29.4, 16.0, and 8.9% respectively.

Table 4: Soil parameters in relation to soil productivity

Soil mapping units	Soil physical characteristics	Bulk density (kg/m^3)	Productivity index (PI) %
UUr1	Well drained, extremely compact, clay, being very hard when dry, friable when moist, sticky and plastic when wet.	1395	29.4
UUr2	Well drained, deep to very deep, compact from the depth of 15 cm.	1360	25.0
UUr4	Well drained, extremely hard when dry, compact and cannot be augured beyond 60 cm,	1560	16.0
RUd	Excessively drained, highly susceptible to erosion, severely degraded, occasionally with topsoils removed compact sandy clay to clay.	1,600	16.0
RUrb	Developed on steep, compact volcanic foot ridges, highly susceptible to erosion.	1340	8.9
BU1	Moderately drained to imperfectly drained, friable to firm sandy clay to clay, occasionally with red mottles.	1150	40.5

Table 5: Soil fertility status of different mapping units

Soil mapping unit	% N	SOC%	P ppm	K m.e.%
UUR1	0.11	1.17	18.06	0.38
UUR2	0.10	1.00	40.00	1.02
UUr4	0.10	1.33	31.67	0.56
RUd	0.08	1.00	35.00	0.36
RUrb	0.15	1.00	35.00	0.58
BU1	0.19	2.00	30.00	0.70

Efficient use of fertilizers involves application of the type and quantity of nutrients, aimed at filling the gaps between the nutrient levels in the soils (expressed in kg/ha) and the quantity required by a given crop per hectare (Sanginga and Woomer, 2009). Therefore, one of the results of establishing the baseline soil fertility status was the determination of the nutrient levels in the soils in kg/ha in different Wards (Table 5). The nutrient levels in the soils are to be matched with the quantity required by the desired crop, and the prescription of the inputs should be done on that basis. For example, Akmal *et al.,* (2010) found that 150 kg/ha of N in combination with 170 kg/ha of P were required for maximum maize production, while Guidoline *et al.* (2001) reported maize yield of 10,000 kg/ha through application 200 kg/ha of N and

120 kg/ha of P. The latter finding is comparable with the maximum production of maize from the research area, calculated, using the effective rain of 582 mm during the growing season (Muya *et al.*, 2015) and water utilization efficiency of 1.25 kg/m^3, given by FAO (1986). Based on these relationships, the levels of nutrients in all the Wards were found to be low except potassium. The soil organic carbon was found to be the most limiting fertility attribute, being much lower than the threshold of 10 tons/ha. The blanket recommendation of applying 50 kg/ha of N and 100 kg/ha of P across the four Wards in Trans-Nzoia County was found to be lower than the quantity recommended (150 and 125 kg /ha of N and P respectively)), based on the mean level of nutrients in the soil, with values of 102.45 and 95.15 kg/ha for nitrogen and phosphorous respectively.

Table 6: Nutrients levels in the soils of different wards

Ward	N kg/ha	SOC tons/ha	P kg/ha	K kg/ha
Cherangani	97.12	0.86	106.83	408.8
S.E.	9.12	0. 863	23.2	54.8
C.V. (%)	31.25	31.86	72.03	44.12
Keiyo	125.82	1.17	76.08	383.25
S.E.	8.954	0.0846	23.2	55.2
C.V. (%)	23.6	23.92	72.03	47.77
Kwanza	81.12	0.74	136.41	535.89
S.E.	4.559	0.743	10.9	78.64
C.V. (%)	15.9	14.54	22.6	41.51
Motosiet	99.92	0.95	72.56	347.67
S.E.	6.938	0.0718	19.17	33.38
C.V. (%)	23.03	25.16	87.65	31.84
Mean	102.45	0.98	95.15	410.34

3.3 Analysis of farmers' practices and yield gaps

The farmers' practices in different Wards, the corresponding maize yield and yield gaps are given in Table 6. The maximum production recorded in the project sites is 9,000 kg/ha, with a yield gap of only 1,000 kg/ha. This was achieved through application of 100 and 50 kg/ha of DAP and CAN respectively. This was followed by 6,750 kg/ha obtained through application of 50 kg/ha of DAP and CAN. The yields from the rest of the sites ranged between 1,800 and 4,500 kg/ha with yield gaps varying from 3,250 to 8,650 kg/ha. The yield gap reflects the seriousness of all limitations in the maize-based systems (Muya *et al.*, 2015). It is an indicator of the biophysical and socio-economic challenges faced by the land users in the real-world farming situations that must be corrected in order to close the gaps. From the biophysical point of view, it reflects on the compounded deficiency of all the soil quality attributes that have significant influence on the crop performance (Driessen, 1997).

The maize yields were found to be highest in Motosiet Ward, followed closely by Cherangani. The lowest yields were obtained in Keiyo Ward, followed by Kwanza despite the relatively high macro-nutrient levels in the two Wards (Figure 1). This could be attributed to lower soil quality caused by the increased physical degradation, resulting into unfavourable soil conditions that constrained the utility of the applied inputs. The unfavourable soil physical constraints included relatively very steep volcanic footridges (RUd and RUrb), extremely compact soils with high volumes of run-off and severely eroded soils, occasionally with topsoils removed. Considering that most important biogeochemical cycles occur in the upper soil horizons, the continuous loss of top soil through unfavourable tillage practices are the major cause of the crop production decline in intensively and frequently cultivated areas (Brunel et al., 2011). Since this erosive phenomenon has differential impacts on the interactions of different processes taking place in the soil profiles in different project sites, they are likely to cause variations in the results of the on-going research whose main objective is to identify climate smart agricultural technologies for enhanced cereal production. Therefore, it is important to identify, delineate and separate the severely eroded areas, non-degraded sites, depositional and imperfectly drained lowlands from well conserved and relatively productive areas. This will facilitate the verification and synthesis of the research results.

Table 7: Farmers' practices, the corresponding maize yield and recommended package

Ward	**Framer No.**	**Fertiliser inputs**		**Maize kg/ha**	**Yield gap kg/ha**
		First application	**Topdressing**		
Motosiet	1	50 kg/ha DAP	50 kg/ha CAN	6,750	3,250
	2	50 kg/ha DAP	50 kg/ha CAN	6,750	3,250
	3	50 kg/ha DAP	50 kg/ha CAN	4,050	5,950
	4	50 kg/ha DAP	75 kg/ha	4,500	5,500
		50 kg/ha DAP	75 kg/ha CAN	3,420	6,580
		75 kg/ha DAP	50 kg/ha CAN	4,050	5,950
	5	100 kg/ha DAP	50 kg/ha CAN	9,000	1,000
	8	100 kg/ha DAP	50 kg/ha CAN	3,320	6,580
	9	100 kg/ha DAP	100 kg/ha	5,850	4,150
	10	100 kg/ha Mavuno	0	4,050	5,950
Keiyo	11	50 kg/ha DAP	25 kg/ha CAN	1,800	8,200
	12	50 kg/ha DAP	0	2,160	7,840
	13	50 kg/ha DAP	50 kg/ha CAN	4,500	5,550
	14	100 kg/ha DAP	50 kg/ha CAN	3,320	6,580
	15	50 kg/ha DAP	50 kg/ha CAN	2,250	7,750
	16	50 kg/ha DAP	50 kg/ha CAN	2,250	7,750
	17	50 kg/ha DAP	50 kg/ha CAN	5,670	4,330
	18	50 kg/ha DAP	50 kg/ha CAN	1,620	8,380
	19	50 kg/ha DAP	50 kg/ha CAN	1,620	8,380
	20	50 kg/ha DAP	50 kg/ha CAN	1,800	8,200
Cherangani	21	50 kg/ha DAP	50 kg/ha CAN	5,670	4,330
	22	50 kg/ha DAP	50 kg/ha CAN	5,670	4,330
	23	100 kg/ha DAP	100kg/ha CAN	4,500	5,500
	24	50 kg/ha DAP	0	1,350	8,650
	25	100 kg/ha DAP	0	5,320	4,780

Kwanza	26	75 kg/ha DAP	75 kg/ha	6,200	3,700
	27	50 kg/ha DAP	50 kg/ha CAN	4,050	5,950
	28	75 kg/ha DAP	75 kg/ha CAN	5,220	4,780
	29	50 kg/ha DAP	50 kg/ha CAN	2,250	7,750
	30	50 kg/ha DAP	50 kg/ha CAN	1,800	8,200
	31	50 kg/ha DAP	0	2,250	7,750
	32	50 kg/ha DAP	0	2,250	7,750
	33	50 kg/ha DAP	50 kg/ha CAN	3,420	6,580
	34	50 kg/ha DAP	0	3,420	6,580
	35	100 kg/ha DAP	75 kg/ha	1,800	8,200
	36	100 kg/ha DAP	75 kg/ha	3,600	6,400
	37	50 kg/ha	0	3,420	6,580

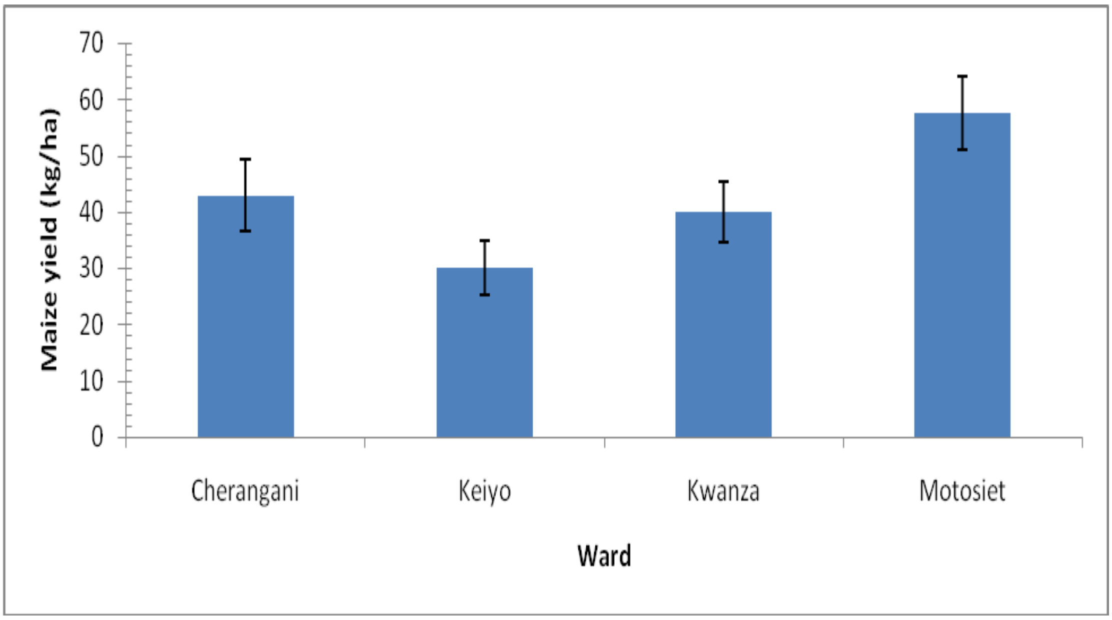

Figure 1: Average maize grain yield in different Wards in Trans Nzoia County

The current maize yield gaps could be attributed to the nutrient deficit, which is the difference between the quantities of fertilizers applied and those recommended, based on the soil test results. However, in order to realize optimum yield, the full recommendation package on fertility management must be tested, validated, disseminated and adopted by the farmers. According to Thomas Fairhurst (2012), testing and validation are required to reliably establish how much input is required to achieve a given yield, which is important for economic analysis. Soil testing alone is not enough; therefore, field experiments are required to caliberate soil test results, verify nutrient deficiencies, establish yield responses to fertilizer and identify risk factors for poor response to fertilizers (Sanginga and Woomer, 2009). The full fertility recommendation package, based on soil survey and test results include:

- Conservation tillage and 10 t/ha of manure to improve soil structure and health
- Reducing soil pH using of 600 kg/ha of dolomitic lime
- Application of 150 and 125 kg/ha of N and P respectively
- Application of 10 kg/ha of zinc sulphate to improve the most limited micro-nutrient (zinc)
- Using Rhizobium inoculated seeds to enhance the level of nitrogen

3.4 The relevance of the envisaged technologies and the predicted impacts

The overall soil-related constraint for all the project sites are surface sealing, compact sub-surface soils (causing low rainwater uptake), low organic matter content and high acidity with over 90% of the sites having pH less than 5.0. Due to low water uptake capacity of most soils, less than 50% of the rainwater is captured and stored in the soil for consumptive use by the crops.

The soils of the research area, being very compact with low water uptake capacity and relatively high volume of run-off, require an intervention that would reverse these undesirable phenomena. For example, Njia (1979) found that maize stover (mulching) effectively controlled run-off through increased surface storage, which in turn, increased infiltration opportunity time. In a study to evaluate the effects of different tillage methods on crop performance and water use efficiency, Kilewe and Ulsaker (1984) came up with the results indicated in Table 7. In this case, conventional contour furrows, wide furrows and mini benches retained all the run-off that resulted in a significantly higher water storage capacity than flat tillage which enhanced yield of maize and water use efficiency. This was attained because upon improvement of soil structure, soil tilth was attained. Hillel (1990) defined soil tilth as a highly desirable soil physical conditions in which the optimally loose, friable and porous assemblage of soil aggregates permits free air and water circulation, relatively high water uptake and storage, unobstructed root growth and germination.

Table 8: Effects of tillage methods on grain yields and water use efficiency

Treatment	**Total water use (mm)**		**Maize yield in kg/ha**		**Water use efficiency kg/ha/mm**	
	Short rains	Long rains	Short rains	Long rains	Short rains	Long runs
Flat	521.2	359.3	3722	256	7.1	0.7
Conventional furrows	506.2	368.8	5242	725	10.4	2.0
Wide furrows	509.2	351.4	5458	844	10.7	2.4
Mini bench	524.2	370.1	4680	643	8.9	1.7

Source: Kilewe and Ulsaker (1984)

4.0 CONCLUSIONS AND RECOMMENDATIONS

The current fertilizer recommendations in the project area were found to be: urea, CAN, DAP and KCL. These recommendations did not consider the variations in soil fertility status resulting from the differential interactions between the soil forming factors and land degradation processes. The variations in these factors, as measured by different productivity indices, accounted for the differences in nutrient levels in different wards. Keiyo Ward had the highest level of nitrogen, being 125.82, followed by Motosiet, Cherangani and Kwanza with values of 99.92, 97.12, and 81.12 kg/ha respectively. Phosphorous level was highest in Kwanza (136.41 kg/ha), followed by Cherangani (106.82 kg/ha) and Keiyo Ward (76.08 kg/ha). The lowest level was recorded in Motosiet with the value of 72.56 kg/ha. Potassium was found to be adequate in all the four Wards with values ranging between 347.67 and 410.34 kg/ha.

The maximum maize production recorded in the project sites was 9,000 kg/ha, with a yield gap of only 1,000 kg/ha. This was achieved through application of 100 and 50 kg/ha of DAP and CAN respectively. This was followed by 6,750 kg/ha obtained through application of 50 kg/ha of DAP and CAN. The yields from the rest of the sites ranged between 1,800 and 4,500 kg/ha with yield gaps varying from 3,250 to 8,650 kg/ha. To narrow the yield gaps, recommended practices, based on the soil test results should be tested, validated, disseminated and adopted by the farmers. These include: cconservation tillage and 10 t/ha of manure to improve soil structure and health; reducing soil pH using of 600 kg/ha of dolomitic lime; application of 150 and 125 kg/ha of N and P respectively; application of 10 kg/ha of zinc sulphate to improve the most limited micro-nutrient (zinc); and Rhizobium inoculated seeds to enhance the level of nitrogen. Motosiet Ward had the highest maize yield, followed closely by Cherangani. The lowest yields were obtained in Keiyo, followed by Kwanza Ward despite the relatively high macro-nutrient levels in the two Wards. This could be attributed to lower soil quality caused by the increased physical degradation, resulting into unfavourable soil conditions that constrained the utility of the applied inputs. The unfavourable soil physical constraints included relatively very steep volcanic footridges (RUd and RUrb), extremely compact soils with high volumes of run-off and severely eroded soils, occasionally with topsoils removed. Therefore, positively high response to fertilizer application is predicated upon elimination of all the correctable limitations associated with increased physical and chemical degradation mainly acidification. On this basis, it is strongly recommended that the envisaged climate smart technologies be geared towards enhancement of water use efficiency through improved soil structure and tilth.

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