Vol. 19(7), pp. 705-714, July, 2023
DOI: 10.5897/AJAR2023.16335
Article Number: 2892AE970971
ISSN: 1991-637X
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African Journal of Agricultural Research

Full Length Research Paper

Adopting a three-strata forage system for an integral food, feed outputs and agro-ecological sustenance

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Received 6 February, 2023; Accepted 31 March, 2023

The exploitation of diverse cropping practices alongside residue incorporation has remained low among small-holder rural farming households in Sub-Saharan Africa. Three-stratum forage system (TSFS) which integrates forages for animal feeds with food crops is a significant sustainable strategy for enhancing residue incorporation. This study was conducted in Busia County in Kenya to; (i) determine the effects of TSFS on yield of diversified food crops grown (ii) to determine the effect of TSFS on growth and physiological responses in food crops grown. In TSFS system, desmodium, brachiaria grass and pigeon peas were grown in the peripheral area of the farm as forages. The treatments were laid on a randomized complete block design at two locations for 3 years (2019, 2020 and 2021), yield in t ha^{-1}, growth and physiological responses in plants measured. The data collected were subjected to Analysis of variance (ANOVA) in SAS software and means separated using LSD at 5% level of significance. Plant growth vigor, physiological responses and yield in t ha^{-1} were significantly higher in TSFS system where residues were incorporated than in no TSFS system (P<0.001). The results revealed that TSFS cropping system could be a better solution to food security and agro-ecological sustenance.

Key words: Three-Strata forage cropping system (TSFS), crop residue incorporation, food security.

INTRODUCTION

Diversified cropping system improves productivity and resilience in agricultural systems. Research towards achieving food security through diversified farming system has received little attention despite its importance in crop production stabilization (Michler and Josephson, 2017). In Kenya, agriculture is one of the key sectors that drive the economy as visualized in vision 2030 (Ndung'u et al., 2011). However, the growth in the sector is constrained by inappropriate farming practices like monocropping, burning of crop debris among others which have contributed to decline in soil fertility and low farm productivity. Most soils in the lowlands regions of Kenya are less productive which has contributed to a decline in crop production. Gicheru (2012) found out that over 11 years crop yields had declined by over 70% due to challenges associated with soil infertility. Soil erosion is

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among the threats to decline in soil fertility and is associated with inappropriate farming practices in Kenya (Gachene et al., 2019).

In Busia County, the agricultural sector is the main source of income as it employs about 78% of the workforce and contributes about 50% to the household incomes (Government of Kenya, 2013a). Even though agriculture is the main source of income, production has remained low considering that 81% of the total land area in the County is arable land.

Generally, the farming practices carried out within the County is majorly subsistence given that 84% of the crops output is used for household consumption (USAID, 2014). The low agricultural production is associated with declining soil fertility and unfavorable climatic conditions, and this contributes to the high food insecurity level in the County as 54% of the population is food insecure with high cases of child malnutrition (Government of Kenya, 2013a). High consumption of cereals and low consumption of animal and vegetable proteins has led to high incidence of malnutrition of children below 5 years where approximately 15.5, 13.3 and 14.8% are underweight, stunted and wasted, respectively (Jela, 2016). To curb these challenges there is need to improve on cropping pattern and diversify the crops grown as one of the possible solutions to enrich diet intake.

Crop resisdues include any plant material that is left on the cultivated land after the valuable part is harvested. It is a practice that is highly recommended as it improves soil structure and supply carborn in the soil upon mineralization. The crop remains are also source of macro and micro nutrients in the soil. Torma et al. (2018) found out that crop residue retention on the soil surface limits water loss and prevents the soil against agents of erosion such as water and wind. Despite the benefits associated with crop residue retention, this practice has remained low in Busia County as residues are used for livestock feeds. Kinyua (2019), found out that crop residues contribute to about 49% of livestock feed in Busia County translating to only 51% crop residue retention in agricultural lands which is low. The low incorporation of crop residues has contributed to most agricultural land to beexposed to agents of erosion. Growing of forages and food crops in a sustainable cropping system could enhance crop residue incorporation. Crop diversification with nutrient dense food crops would enhance both crop productivity and soil fertility improvement. Through TSFS cropping system, the crops provide total ground cover while short maturing legumes such as, cowpeas (*Vigna unguiculata*) and beans (*Phaseolus vulgaris* L.) can act as green manure. In addition, planting of forages such as desmodium and brachiaria as hedgerows for livestock feeds could also narrow the gap of using crop residues as animal feeds.

The three-strata forage system (TSFS) technology integrates nutrient dense crops into different vertical and horizontal levels by using forages as border plants (Nitis et al., 1995). The food crops are planted in the core area while the forages on the peripheral areas of the farm thereby providing protection to the food crops. The TSFS system enables the farmer to harvest both food crops and forages from the same piece of land. The forages could be grasses, shrubs, ground legumes or feed trees planted as livestock feeds that can be harvested and fed to livestock all year round (Nitis et al., 1995). The forages like *Medicago sativa*, *Pennisetum purpureum, Calliandra calothyrsus* could also be used as alternative strata forages to the ones used in this study in order to create opportunity for crop residue retention.

The aim of this study was (i) to determine the effect of TSFS system on yield of the selected food crops grown, ii) to determine the effect of TSFS system on the growth and physiological responses of selected food crops grown which included cereals (maize), legumes (beans and cowpeas), and African leafy vegetables (crotalaria, amaranth and pumpkin). It was hypothesized that crop residues incorporation in TSFS has effect on growth and performance of the selected food crops.

MATERIALS AND METHODS

Experimental site description

This study was conducted in Ng'elechom (0.5644^o N, 34.1588^o E) and Obekai (0.5121^o N, 34.2095^o E) locations within Teso South Sub-County in Busia County, Kenya (0° 27' 38.7684'' N and 34° 6' 41.2632'' E). The soils in Ng'elechom are gleyic acrisols consisting mainly of unconsolidated sand deposits while Obekai has humic cambisols with high clay content and good drainage (Jaetzold et al., 2012). Both locations lie within lower midland cotton zone (LM3), Obekai has an altitude of 1202 meters above sea level (m.a.s.l) while Ng'elechom has 1128 m.a.s.l (Jaetzold et al., 2012). The two locations receive an annual precipitation range of 1,000 mm-1,500 mm and have daily mean temperature range of 14-30^{o}C (Jaetzold et al., 2012). This experiment was conducted between September-December 2019 (short rains), April-August 2020 (long rains) and April-August 2021 (long rains) cropping seasons.

Planting materials

A set of diverse food crops were selected and grown including cereals: *Zea mays* (maize), legumes: *Phaseolus vulgaris* (climbing beans), *Cicer aerietinum* (chickpeas), *Arachis hypogaea* (groundnuts) and African leafy vegetables: *Vigna unguiculata* ((cowpeas), *Cucurbita pepo*(pumpkin), *Amaranthus spp*. (amaranth) and *Crotalaria spp*. (crotalaria). The 8 foodcrops were selected on the basis of the regional adaptability, nutrient dense and provision of good ground cover especially the African leafy vegetables like pumpkins. In TSFS, the strata forages planted were desmodium (*Desmodium uncinatum*), Brachiaria grass (*Brachiaria decumbens*) and pigeon peas (*Cajanus cajan*).

Experimental design and treatments

The experiments were laid out in randomized complete block design (RCBD) with three replications per location. The plots were sub-divided into four sub-plots with each subplot having different set of crops as per the lay out indicated in Table 1. In both cropping systems, crop rotation was practiced during the second and third seasons as a way of randomizing the crops at plot level.

Field preparation and management

The land was ploughed using oxen and seedbed prepared to improve the soil tilth depending on the seed size. In the first plot of polyculture system consisting of maize, beans and pumpkin, one maize seed was sown per hill at a spacing of 75 cm × 25 cm to give a plant population of 54,595 plants ha^{-1}.

The climbing beans (*P. vulgaris L.*) were also sown one seed per hill in between the maize rows at a spacing of 75 cm × 30 cm (44,445 plants ha^{-1}) and pumpkins were planted at a spacing of 1.5 m × 1.5 m (4,445 plants ha^{-1}) in an alternate row of maize and beans.

In the second plot, chickpeas were planted as a sole crop at a recommended spacing of 40 cm x 20 cm (125,000 plants ha-^{1}). In the third plot an inter-crop of cowpeas and amaranth, cowpeas were planted at a spacing of 60 cm × 20 cm (83,334 plantsha^{-1}) with double row of amaranth drilled in between and later were thinned to a spacing of 60 cm × 20 cm (83,334 plants ha^{-1}) two weeks after emergence.

In the last plot, crotalaria (*Crotalaria* spp) seeds were drilled and later thinned to a spacing of 60 cm × 20 cm (83,334 plants ha^{-1}) two weeks after emergence.

All the plots measured 4.5 m × 4.5 m = 20.25 m^2 (2.025 10 x 10^{-3} ha) and thus the application of fertilizer was equal with 6 furrows of fertilizer in each plot. A compound fertilizer, grade 23-23-0 (NPK^{TM}), was used during planting which supplied an equivalent of 11.5 kg N ha^{-1} and 11.5 kg P_2O_5 ha^{-1}. A 50 cm alley strip was maintained between the crops and forages.

The inner-most stratum consisted of silver-leaf desmodium planted at a spacing of 30 cm × 30 cm to achieve a seeding rate of 2.5 kg ha^{-1}. The second stratum consisted of *Brachiaria ruziziensis* variety *Mulato*. The *B. ruziziensis* sets were planted at a spacing of 50 cm apart, distance between the inner and the second stratum was 50 cm. A medium- maturing pigeon peas (*C. cajan*) variety *Mbaazi*-1 was planted in the outer-stratum at a spacing of 50 cm × 10 cm at a seed rate of 12 kg ha^{-1}. The crops were manually weeded twice in the 4th and 9th week after germination.

Thunder^{TM} (*Imidacloprid* 100 g/L + *Betacyfluthrin* 45 g L^{-1}) was used at the rate of 100 ml ha^{-1} for protection against common insect pests in pigeon peas)(*C. cajan*) during flowering. There was no pesticide used on the food and vegetable crops.

A field trial experiment was set earlier (April-August 2019) before the beginning of the first season of the experiment. This was done in order to provide TSFS enough time to establish.

After the first cycle of cropping season all the residues obtained from crops were chopped and incorporated in the TSFS system. However, the plots in no TSFS treatment combinations were left bare;' which was done with assumption that residues were used as animal feeds, a common livestock feeding strategy in the locality. Similar crops and spatial arrangements were planted during the second and the third cropping seasons for similar set of data for comparative purposes.

Data collection and analysis

Data were collected on growth, physiological response, yield and yield components. The data collected for each crop depended on the value of the parameter in assessing its performance. Five plants of each crop species in a sub-plot except those from the guard rows were randomly selected and the parameters taken. The data collected on pumpkin, groundnuts, chickpeas and pigeon peas in the three seasons at both locations were excluded from the stages due to heavy rains. (The data collected were few since we lost the crops in different stages due to heavy rains so they were excluded from the analysis to avoid biasness).

For maize (*Z. mays*), the plant height was determined at 30 days after planting and at maturity by measuring the height from the ground level to the leaf collar of the highest fully expanded leaf using a ruler. The chlorophyll content **(**μmol m^{-2}) in leaves and stomatal conductance (mmol m^{-2} s^{-1}) were measured 60 days after sowing using chlorophyll meter model CCM-200 and SC-1 leaf porometer, respectively. The above- ground biomass (g cm^{-2}) was determined at maturity after harvesting the cob, 100 seed weight was obtained through physical counts and grain yield determined and expressed in g plant^{-1} $^{-2}$ and later extrapolated to t ha^{-1} on dry weight basis.

For the legumes planted (beans, groundnuts and cowpeas) the plant heights (cm) were determined at 30 days after planting and at maturity by measuring the height (cm) from the ground level to the leaf collar of the highest fully expanded leaf using a ruler. The chlorophyll content **(**μmol m^{-2}) in leaves and stomatal conductance (mmol m^{-2} s^{-1}) were measured 60 days after sowing using chlorophyll meter model CCM-200 and SC-1 leaf porometer, respectively. The above ground biomass (g plant^{-1}) was determined at maturity after pod picking; number of pods counted per plant and grain yield determined and expressed in g plant^{-1} and later extraporated to t ha^{-1} on dry weight basis. The harvest index (HI) ratio of the maize and the legumes were determined by calculating the ratio of grain yield to total biomass using the following formula (Kemanian et al., 2007).

$$\text{Harvest index(HI)} = \frac{\text{Grain yield}}{\text{Total biomass}}$$

The African leafy vegetables (cowpeas, giant amaranth and crotalaria) data on chlorophyll content **(**μmol m^{-2}), stomatal conductance (mmol m^{-2} s^{-1}) in leaves were measured using chlorophyll meter model CCM-200 and SC-1 leaf porometer, respectively, 60 days after planting. The fresh leaves of cowpeas and crotalaria were harvested in the entire plot twice during the growing seasons at 30 and 45 days after germination, and their respective weights recorded. After wards, the vegetables were left to flower and obtain achieve physiological maturity. The grain yield (g cm^{-2}) for the giant amaranth and cowpeas were measured at maturity (85 days after sowing) and yield expressed in (t ha^{-1}).

All the data collected were first subjected to Shapiro-Wilk's test (W) to check if the distribution of the values were statistically different from the normal distribution (Hanusz et al., 2016). The data were then subjected to the Analysis of Variance (ANOVA) using PROC GLM followed by PROC SORT procedure in SAS to compare the performance of each crop both in TSFS and no TSFS (SAS Institute version 9.4, 2002). The Fisher's protected least significant difference (LSD) test at 5% level of significance was adopted for mean separation following the formula below (Williams et al., 2010).

$$W = \frac{(\sum_{i=1}^{n} a_i x_{(i)})^2}{\sum_{i=1}^{n} (x_i - \overline{x})^2}$$

RESULTS

The effects of three-strata forage cropping system (TSFS) on grain yield and yield components of food crops

Results showed enhanced crop performance in the TSFS plots than those planted in the no TSFS. Yield in t ha^{-1}

Table 1. An experimental field layout.

Maize/beans/pumpkin (TSFS)	Chickpea (TSFS)
Cowpea/amaranth (TSFS)	Crotalaria/groundnut (TSFS)
Maize/beans/pumpkin (no TSFS)	Chickpea (no TSFS)
Cowpea/amaranth (no TSFS)	Crotalaria /groundnut (no TSFS)

Source: Author

and yield components of grain crops like maize and beans were significantly higher at p<0.001 in the TSFS compared to the no TSFS (Figure 1a, b). The same trend was also observed in African leafy vegetables (cowpeas, amaranth and crotalaria) (Figures 2 and 3). Growth and physiological responses in crops were higher in crops grown in the TSFS compared to those in no TSFS system (Tables 2 and 3).

The performance of maize and beans in TSFS and in no TSFS over the growing seasons

Figure 1 shows the performance of maize and beans in TSFS and in no TSFS over the growing seasons. In TSFS cropping system, maize yielded 6.06 t ha^{-1}, 6.51 t ha^{-1} and 7.92 t/ ha^{-1} during the first, second and third seasons, respectively, while in the no TSFS, maize yielded 5.43 t ha^{-1}, 5.86 t ha^{-1} and 6.12 t ha^{-1} during the first, second and third season, respectively (Figure 1a). Results revealed about 31% and 13% yield increase from the first to the third season in TSFS and in no TSFS cropping system, respectively (Figure 1a). In the TSFS cropping system, beans (*P. vulgaris*) yielded 1.15 t ha^{-1}, 1.34 t ha^{-1} and 2.03 t ha^{-1} during the first, second and third seasons, respectively, while in the no TSFS, 1.12 t ha^{-1}, 1.15 t ha^{-1} and 1.75 t ha^{-1} of beans were obtained during the first, second and third season, respectively (Figure 1b). This translated to about 77% and 57% yield increase from the first to the third season in TSFS and in no TSFS cropping system, respectively.

The effects of location on the performance of maize, beans and groundnuts

Crop environment emerged as a major contributor to crop response in TSFS. Results showed that significant variations existed between the two locations for the agronomic traits evaluated. Plant vigor, plant height at maturity, biomass, and grains per cob, HI, 100 seed weight and yield of maize were higher in Obekai than Ng'elechom. Maize crop yielded higher in Obekai than Ng'elechom. However, there was no significant impact (P>0.05) observed on chlorophyll content and stomatal conductance in maize leaves (Table 2). In beans, plant vigor, chlorophyll content, plant height, biomass, number of pods per plant, 100 seed weight and yield were higher in Obekai compared to Ng'elechom (P < 0.001).

Response of African leafy vegetables to the TSFS cropping system

African leafy vegetables in the study were amaranth, cowpeas and crotalaria. They yielded higher in the TSFS cropping systems than in no TSFS system (P<0.001). Plant vigor, chlorophyll content and yield (t ha^{-1}) were notably higher in the TSFS than in the no TSFS. In cowpeas, the stomatal conductance in leaves was higher in plants grown in the TSFS than in no TSFS. However, there was no variation in plant height and biomass for both cpeas and amaranth grown in TSFS and in no TSFS system (P>0.05) (Table 3).

Effect of location and season on the performance of amaranth, crotalaria and cowpeas

The leafy vegetables performed significantly different (P<0.05) in the two locations. Cowpeas and amaranth yielded slightly higher in Obekai than Ng'elechom (Figure 2). There was a significant increase (P<0.001) in harvestable leaves of Crotalaria and Cowpeas (g $m-^{2}$) of in the third season compared to the the second and first seasons (Figure 3a). A significant (P<0.05) yield increase of about 49% and 40% was observed in cowpeas grown in the TSFS and in no TSFS cropping system, respectively. Crotalaria on the other hand recorded a yield increase of about 72% and 34% in the TSFS and in no TSFS, respectively (Figure 3a). The productivity on the fresh weight basis of the second harvest were higher compared to the first harvests (Figure 3b).

The performance of strata forages in TSFS cropping system

The TSFS had forages alongside crops unlike in the no TSFS cropping system. The two forage species performed significantly different (P<0.05) in the two locations.

Brachiaria ruziziensis yielded significantly higher (P<0.01) in Ng'elechom (8.79 t ha^{-1}) than in Obekai (7.14 tons/ha) (Figure 4). On the other hand, Desmodium

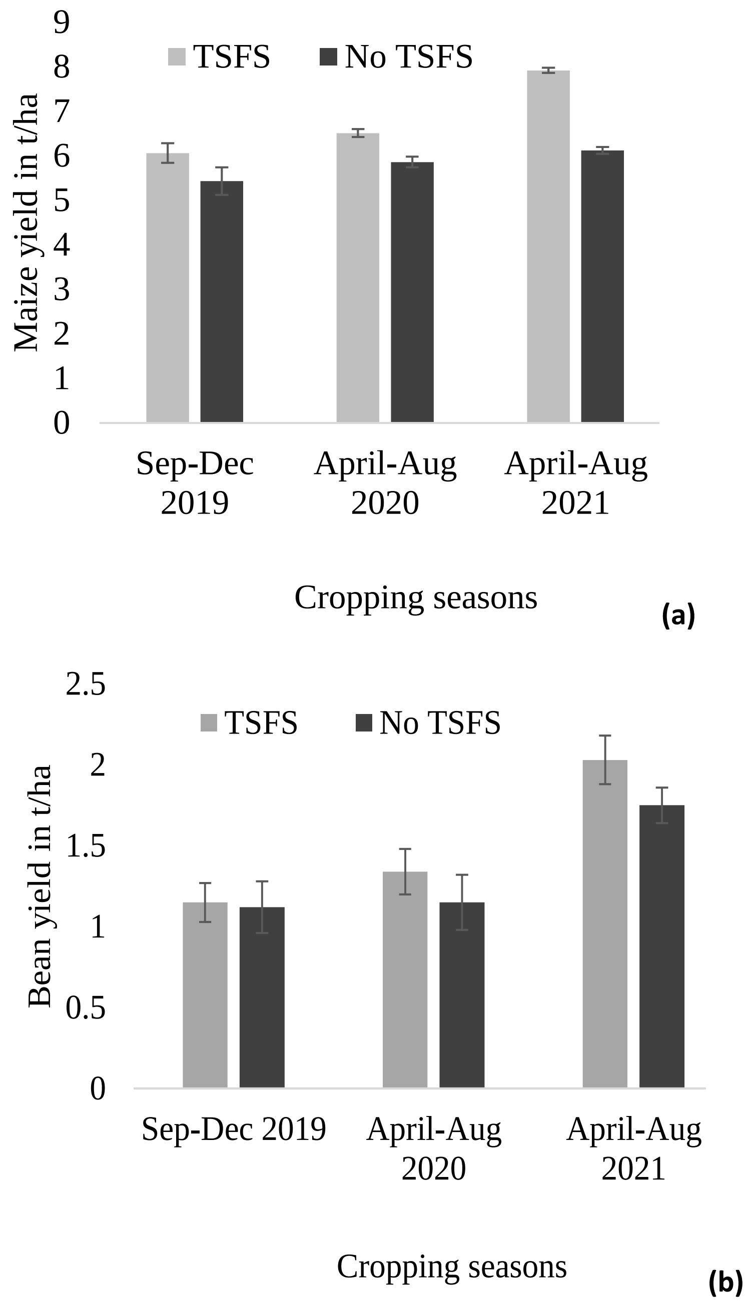


Figure 1. The yield of maize and beans in TSFS and in no TSFS during the three growing seasons.
Source: Author

produced higher yield Obekai (2.81 tons ha^{-1}) than in Ng'elechom (2.6 tons ha^{-1}) (Figure 4).

DISCUSSION

Effects of TSFS cropping system on physiological responses in plants and yield of the food crops

The retention of crop residues in the field could have contributed to increase in soil nutrients which were further absorerd by the crop roots and hence chlorophyll increase in plant leaves. These results are in agreement with findings reported by Aminifard et al. (2012) and Sikuku et al. (2016).

The contribution of the TSFS on enhanced crop productivity could be attributed to positive interaction between strata crops and crop pests. Planting of *Brachiaria* and Desmodium as hedgerows could have played a role in curbing common pests which could

Table 2. Growth, physiological responses, yield and yield components of maize and beans in two locations.

Crop	Location	Plant vigor (cm)	Chlorophyll content (µmol m^{-2})	Stomatal conductance (mmol m^{-2} s^{-1})	Plant Height (cm)	Biomass (g/plant)	Grains/cob and pods/plant	Harvest Index	100 seed weight (g)	Yield (t/ha)
	Obekai	53.27^{a}	51.24^{a}	24.59^{a}	140.36^{a}	247.76^{a}	453.91^{a}	0.54^{a}	360.31^{a}	7.56^{a}
Maize	Ng'elechom	49.59^{b}	50.27^{a}	24.49^{a}	91.34^{b}	165.22^{b}	384.81^{b}	0.51^{b}	308.53^{b}	5.43^{b}
	LSD(0.05)	1.87	1.12	0.90	4.81	4.45	31.65	0.02	13.40	0.64
	Obekai	28.15^{a}	25.72^{a}	24.57^{a}	81.44^{a}	133.74^{a}	14.92^{a}	0.31^{a}	265.81^{a}	1.49^{a}
Beans	Ng'elechom	25.09^{b}	22.39^{b}	23.87^{a}	75.40^{b}	122.14^{b}	13.67^{b}	0.32^{a}	234.93^{b}	1.35^{b}
	LSD(0.05)	1.71	3.31	1.09	4.20	6.32	0.96	0.03	2.45	0.24

Means followed by the same letter within a column are not significantly different at ($p>0.05$).
Source: Author

Table 3. Growth, physiological response, yield and yield components of amaranth and cowpeas in TSFS and in no TSFS cropping systems.

Crops	Cropping system	Plant vigor (cm)	Chlorophyll content (µmol m^{-2})	Stomatal conductance (mmol m^{-2} s^{-1})	Plant Height (cm)	Biomass (g plant^{-1})	Yield (t/ha)
	TSFS	23.41^{a}	21.81^{a}	25.15^{a}	129.22^{a}	183.56^{a}	1.58^{a}
Amaranth	No TSFS	22.01^{b}	19.88^{b}	25.11^{a}	115.67^{a}	179.72^{a}	1.17^{b}
	LSD(0.05)	1.29	0.98	1.77	16.68	8.15	0.15
	TSFS	28.65^{a}	69.21^{a}	26.03^{a}	69.27^{a}	103.97^{a}	2.04^{a}
Cowpeas	No TSFS	26.48^{b}	63.71^{b}	24.55^{b}	66.75^{a}	97.63^{a}	1.71^{b}
	LSD(0.05)	1.73	2.84	0.83	4.32	12.82	0.36

Means followed by the same letter within a column are not significantly different at (*P>0.05*).
Source: Author

attack crops thereby increasing crop yields in TSFS cropping system. These results are in agreement with reported results of Hailu et al. (2018), who reported that planting of desmodium and Brachiaria grass as intercrops with maize proven to be effective for controlling stemborers, fall army worm and the parasitic striga weed. The 'push-pull' companion cropping systems reduced the mean maize damage score of fall armyworm by 168%, compared with the control and this translated to 46.80 and 51.11% increase in maize grain yield and biomass yield, respectively (Yeboah et al., 2021). The inclusion of pigeon peas also acted as windbreaks thereby protecting the crops within the TSFS from external factors like strong winds and this made the crops to perform better as compared to those in the no TSFS. The noted higher yield obtained in a TSFS than in no TSFS cropping system could also be as a result of crop residue incorporation and inclusion of cover crops in the system.

The crop residues act as habitat and substrate for soil flora and fauna and hence increase soil nutrients subject to mineralization (Pal et al., 2016). Other benefits include soil surface cover thereby decreasing soil erosion and also enhancing soil moisture retention, which could not

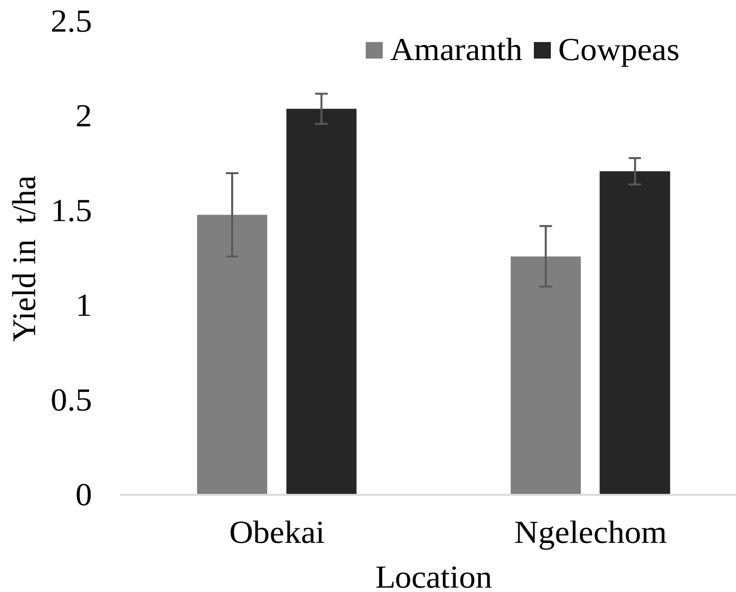


Figure 2. The performance of amaranth and cowpeas (t ha^{-1}) in Obekai and Ngelechom location.
Source: Author

be guaranteed in the no TSFS. The noted vigorous crop growth could be explained on the basis of the differences in soil organic matter.

Consistent addition of crop residues is expected to sustain an improved soil structure which serves to increase both water infiltration and storage (Turmel et al., 2015). A well-structured soil sustains root growth by enabling the growing plants to capture a sufficient proportion of the available nutrients (White et al., 2013a, b).

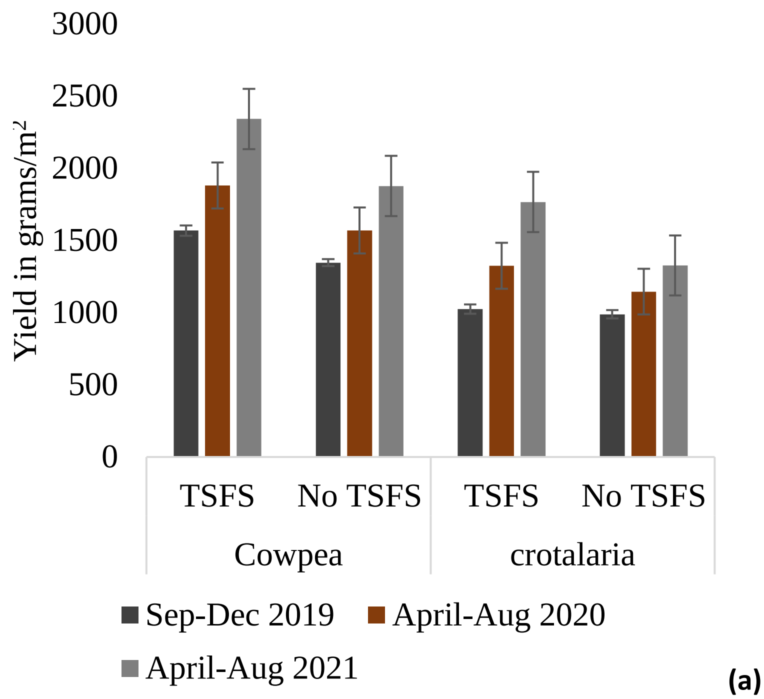
The forages included in the TSFS could be used as feed to replace crop residues in feeding livestock. The trend in crop performance seemed to depend on residue incorporation. The crop residues incorporated decomposed yielding organic matter in the soil. The organic matter helped in adsorbing and retaining nutrients in a form that can easily be accessed by plants. The plants absorbed the nutrients through the roots and thus helped in crop yield optimization.

Hijbeek et al. (2017) found out that there is a positive correlation between crop yield and soil organic matter content in the soil. These results are consistent with the findings of Uzoh et al. (2019) who reported that crop residue incorporation and nitrogen fertilizer application significantly improved soil nitrogen and maize grain yield over non-residue incorporation. Crop residue incorporation as a source of organic matter resulted in 12 and 16% higher yield in maize and sugar beet respectively compared to other sources (Piccoli et al., 2020).

The TSFS with integrated forages for feed had added advantage over the no TSFS cropping system. The two forage species performed differently in the two locations. Brachiaria grass yielded higher in gleyic acrisols soils with low fertility in Ng'elechom than humic cambisols in Obekai. Brachiaria grass is adaptable and more resistant in soils with low fertility due to its capacity to absorb and accumulate silicon in aerial parts (Melo et al., 2003). Brachiaria grass does well in sandy soils compared to clay and loamy due to its high tolerance to both alkalinity and salinity. Desmodium on the other hand tolerates slight acidity and hence performed better in humic cambisols soils in Obekai than acrisols soils in Ng'elechom. Pitman and Sotomayor (2000) reported that desmodium has the capacity to tolerate aluminium toxicity in soil and this makes it to tolerate slight acidity as well. The addition of forage crops could be added advantage to the farmers since it guarantees ready feeds that can be used directly in the homesteads or sold for income.

The effects of location and season on growth and yield of selected food crops

In regard to location, there was variation in growth, physiological responses, yield and yield components of the selected food crops. Even though the two locations lie within the same agro-ecological zone (LM3 zone), the crops grown in Obekai performed slightly higher than those grown in Ng'elechom. The observed differences could be due to differences in soil type. Obekai has humic cambisols soils which are well drained and contain high content of humic top soils which supported the crop



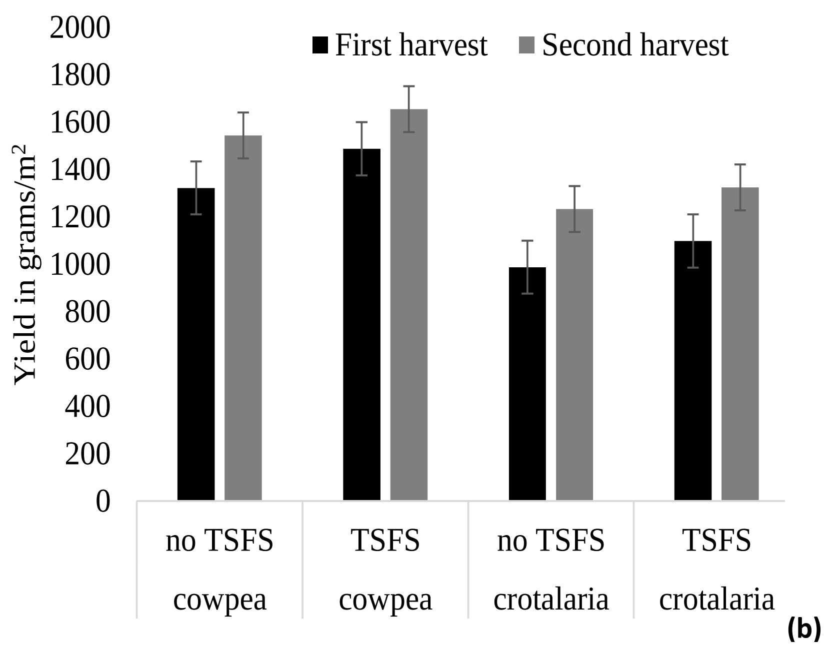


Figure 3. Comparison of cowpea and crotalaria (g m^{-2}) across seasons (a) and differences in yield between 1st and 2nd harvests (b) at ($P<0.05$).
Source: Author

growth unlike Ng'elechom with gleyic acrisols soils consisting of unconsolidated sand deposits. Cambisols soils contain high content of clay (Abdissa et al., 2011) while acrisol type of soil has very low inherent chemical fertility and water holding capacity (Pardo et al., 2003). These results are in agreement with Aruani et al. (2014), who found out that yield of *Pyrus communis* had significant differences depending on soil groups and growing seasons.

During the third cropping cycle, a significant yield

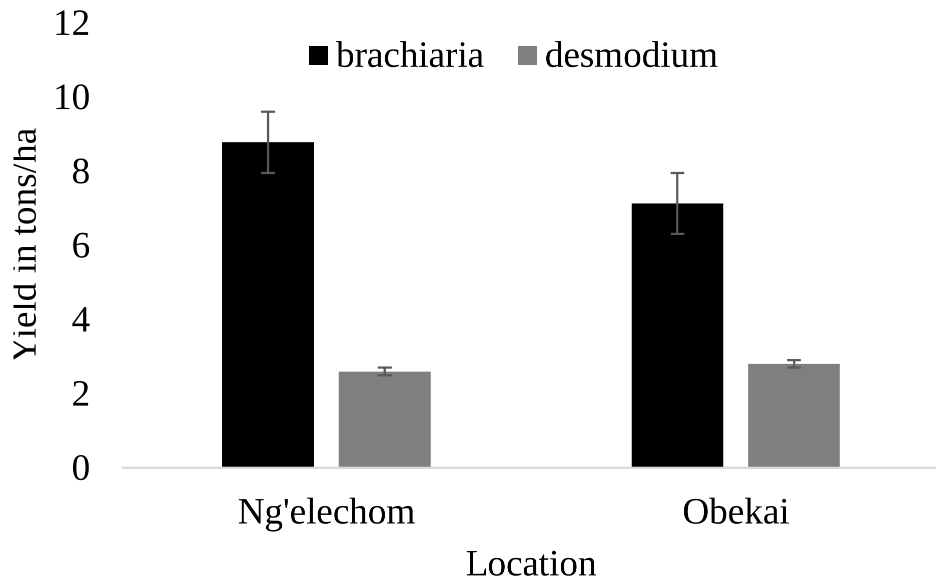


Figure 4. Fresh biomass of brachiaria grass and desmodium during the third season.
Source: Author

increase was observed in crops grown both in the TSFS and in no TSFS cropping system. Even though yield increase was observed in both systems, crops grown in TSFS yielded higher compared to those in no TSFS. The forages acted as hedgerows in the cultivated plots thereby creating a barrier preventing soil loss. During heavy rains, the movement of water could be slowed down as it runs through the hedgerows and this helps in reducing soil erosion. Through this system, all the nutrients were held in the cultivated area making it more fertile than in no TSFS and this could be a contributing factor to higher increase in yield. These results are in agreement with the findings of Donjadee and Tingsanchali (2013) who found out that a vetiver (*Chrysopogon zizanioides*) hedgerow can reduce up to 31-69 and 62-86% of runoff volume and soil loss, respectively compared to non vetiver hedgerow. The long rains in the third season supported the plant growth and general performance of crops. The crops are dependent on water during their entire lifecycle in order to survive and thrive and therefore water availability for crop use enhanced good production.

These results are in agreement with the findings of Mkonda (2014), who reported that there is a relationship between rainfall variability and crop production.

The window of time between the time of residue incorporation and the third season also gave the soil microorganisms' opportunity to breakdown the residues into usable nutrients thereby adding organic matter into the soil.

The available nutrients were utilized by plants during the third season thereby increasing yield of the selected crops. According to Rengel and Bowden (2006), the nutrient content in crop residues is not readily available to plants primarily after incorporation hence there is need for mineralization in order to convert them into a form available for plants.

Conclusion

This study is an effort to determine an alternative cropping system that can provide food, feed and agro-ecological sustenance overtime. The results demonstrate the effectiveness of three-strata forage system (TSFS) on crop and forage performance in the same piece of land. This may present a significant contribution to farmers struggling to balance crop residues for livestock consumption and incorporation to boost soil fertility.

CONFLICT OF INTERESTS

The authors have not declared any conflicts of interests.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to the farmers within Teso south Busia County for allowing them to do their research work on their farms and for being part of the team. Their sincere gratitude also goes to Education and Training for Sustainable Agriculture and. Nutrition in East Africa (EaTSANE PROJECT) for the financial support. They also acknowledged Egerton University institution for their support during the entire

research period.

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