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Yield advantage and profitability of selected climate-smart technologies: Findings from demonstration plots in Northern Uganda

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Abstract

Climate-smart agriculture (CSA) is viewed as a potentially effective intervention to address low agricultural productivity in Sub-Saharan Africa (SSA), while strengthening farmers' capacity to adapt to the effects of climate change. We therefore conducted a study to examine maize yield response to three CSA practices – ripping, permanent planting basins and alley cropping. The profitability of their use with and without fertiliser application was also evaluated. It was deduced from the study that ripping, planting basins and alley cropping with Gliricidia (Gliricidia sepium) *gave the greatest yield advantage. of 457.1 kg/acre, 456.7 kg/acre and 437.2 kg/acre respectively. Fertiliser application significantly increased the yield advantage, but this increment did not necessarily translate into cost-effectiveness due to the associated costs. In fact, minimum tillage interventions were more profitable without fertiliser application, and at some locations responded poorly to fertiliser application. These variable responses indicate the need for developing site-specific CSA interventions for improved maize productivity and profitability.*

Key words: alley cropping, minimum tillage, economic benefit, yield

1. Introduction

Agricultural systems all over sub-Saharan Africa (SSA) are increasingly experiencing pressure relating to food production. In fact, food demand in Africa is expected grow by 60% before 2030 (Townsend 2015; Food and Agriculture Organization [FAO] 2019). This means that the current food production, estimated at 740 million tons (FAO 2020), will have to increase at least two-fold if food security is to be achieved within the next decade. Regionally, farmers have to cope with challenges of declining soil fertility, land fragmentation, and climate change and variability. Worse still, current smallholder productivity in SSA is only half of the average yield in all developing countries, and merely 20% of the average yield of developed countries (African Development Bank [AfDB] 2022). As in the rest of Africa, declining crop productivity is one of the challenges faced by farmers in Uganda, particularly in Northern Uganda. This is mainly attributed to limited use of inputs such as fertiliser and improved seed, moisture stress due to climatic variability, and poor farming practices (Mubiru *et al*. 2017; AfDB 2022). As a result, production is way below potential estimates, leading to massive yield gaps. For example, the maize yield in Uganda stands at 3.0 t ha^{-1}, compared to South Africa (4.4 t ha^{-1}), North America (10.5 t ha^{-1}), South America (5.7 t ha^{-1}) and Asia (5.4 t ha^{-1}), (FAO 2022).

Climate-smart agriculture (CSA) practices have emerged as potential solutions to low agricultural productivity among various farming communities in SSA (AfDB 2022). According to Lipper *et al*. (2014) and the World Bank (2023), CSA is defined as an approach for transforming and reorienting agricultural development under the new realities of climate change. It can also be viewed as "agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces/ removes greenhouse gases (mitigation), and enhances achievement of national food security and development goals" (Pingali *et al*. 2019:229). In this definition, the principal goal of CSA is identified as food security and development, while productivity, adaptation and mitigation are identified as the three interlinked pillars necessary for achieving this goal (see also Lipper *et al*. 2014; World Bank 2023).

Examples of CSA interventions include soil fertility management, using drought-tolerant maize varieties, crop diversification, intensive catfish farming, timely planting, biogas production, use of rip lines and permanent planting basins, and alley cropping. Planting basins and ripping are collectively known as minimum tillage (MT) (CIAT & BFS/USAID 2017). Planting basins are a tillage system with minimal soil disturbance, for which permanent planting stations (or basins) are dug using manual labour. Ripping is a tillage method in which the soil is left undisturbed except where planting lines are opened to a depth of about 15 cm along rip lines made by animal- or mechanically drawn rippers. According to Wolz and DeLucia (2018), alley farming is the production of crops within alleys formed by rows of fast-growing leguminous trees. The trees are pruned and can be used as mulch, green manure, or livestock feed. Alley farming is one of the sustainable farming techniques that could eliminate fallow periods.

Thus, numerous studies conducted over the past few years have shown that CSA practices can increase productivity and food security (Zhao *et al*. 2023). Examples are the adoption of drought-tolerant maize in Uganda and Kenya (Fisher & Carr 2015; Wanjira *et al*. 2022), the diversification of cropping systems in the rice-growing regions of Bangladesh (Assefa *et al*. 2021), and the application of conservation farming for maize production in Zimbabwe (Mhlanga *et al*. 2022).

Despite the potential benefits of CSA and its active promotion by development agencies in SSA since the 1980s, adoption remains low. For instance, implementation of practices such as MT and agroforestry with nitrogen-fixing trees stood at less than 30% in Uganda and Zambia in 2017 (CIAT & BFS/USAID 2017; CIAT & World Bank 2017)

Some factors that discourage adoption are: Labour-intensive CSA technologies (like pond construction), which may place additional burden on women and children; where new practices challenge long-established beliefs and norms or require high levels of attitudinal and behavioural change (such as substituting ploughing with ripping); and where the supporting services (extension, finance, markets and subsidies) are weak or not supportive of the technologies being promoted (for instance extension continuing to promote non-CSA methods, lack of subsidised inputs) (Ogisi & Begho 2023). On the other hand, enabling factors that drive adoption are: CSA productivity and profitability; having appropriate skills and access to resources (inputs, markets) and services (extension, weather and market information, finance); having numerous options of CSA technologies to choose from; affordability and CSA technologies that bring short-term benefits (Antwi-Agyei *et al*. 2021; Negera *et al*. 2022) This implies that CSA technologies will only be adopted where they bring benefits to farmers that can be felt, especially if they are profitable.

Hence, this study was carried out to validate the appropriateness of selected CSA practices for smallholder farming and to examine the profitability of CSA technologies using participatory farmer field trials. Specifically, this paper examines the short-term yield advantage and economic benefits of planting basins, rip lines and alley cropping in Northern Uganda.

2. Methodology

2.1 Study location

Evaluation trials were established in three locations on farmers' fields in Gulu, Pader and Lamwo districts, and on-station in Kitgum district. These districts are located in the northern agroecological zone of Uganda, in Acholi sub-region (Figure 1), between 2.53987°N and 3.88816°N latitude and between 32.1934°E and 33.74237°E longitude (Google 2021). The study area has a population of about 1 790 700 inhabitants (Uganda Bureau of Statistics [UBOS] 2020) and covers an area of 16 369 km^2.

2.2 Trial set-up and design

Evaluation sites that measured 100 m by 40 m were divided into three blocks. Each block contained one of each climate-smart technologies (alley cropping, ripping and permanent planting basins), with conventional farming practice as the control, and measured 33 m by 40 m. Thus, a block was divided into four equal plots, each containing a treatment (technology) allocated using random numbers. The blocks containing rip lines and permanent planting basins were further divided into sub-blocks, with and without fertiliser. The rip lines were made 75 cm apart and 15 cm deep using the Krammer-3 ripper. The dimensions of the planting basins were 35 cm long x 15 cm wide x 15 cm deep, and these were placed 30 cm apart. The block with alley cropping contained three tree species, namely

Gliricidia (*Gliricidia sepium*), Leuceana (*Leuceana leucocephala*) and Calliandra (*Calliandra calothyrus*). The tree/shrub seedlings used for these trials were established two months earlier in nursery beds near the demonstration sites. Blocks containing rip lines and permanent planting basins were maintained by means of herbicide spraying. Blocks containing the control plots and alley cropping were managed through regular hand hoeing. Generally, the evaluation sites were established on fairly flat terrain, devoid of anthills, at least 500 m from major roads, and were not adjacent to any forests or dump sites. The test crop that was used in this trial was maize (Longe 5 variety), planted in September 2018 (second planting season) and May 2019 (first planting season).

Figure 1: Map of Uganda showing the location of the study area in Acholi sub-region.
Source: United Nations High Commission for Refugees ([UNHCR] 2020).

2.3 Data collection

Yield data represents weights for dried and shelled maize grains harvested ninety days after planting. Each sampling unit comprised of six (6) clustered maize plants chosen randomly to represent one square metre of experimental plot. Soil nitrogen (N) was determined using the Palintest photometer (SKW-500) at harvesting.

2.4 Data analysis

The field data collected was entered into and stored in the MS Excel software program, followed by subsequent exportation into Stata (Version 13) software for analysis. ANOVA was used to determine the variability between treatments and, where necessary, post-hoc tests were conducted using Tukey's honestly significant difference (HSD). Yield advantage was deduced from paired sample t-tests for means, and histograms were generated using MS Excel. Economic analysis was computed by incorporating all the associated costs per treatment (Table 1) against the predicted income from maize, which was put at Uganda shillings (Ugx)/= 1 000 per kilogram. The common production costs included planting, harvesting, threshing, drying, fall army worm spraying and seed acquisition. On the other hand, treatment-specific costs were ox-drawn ripping, establishment of planting basins, herbicide spraying for the MT practices, seedling establishment, cutting back of alley trees, and ploughing biomass into soil for alley cropping.

Table 1: Cost of CSA practices evaluated in 2018 and 2019

Item	**Amount in Uganda Shillings per acre**					
	Alley cropping	**Conventional farming practice**	**Ripping**		**Planting basins**	
			No fertiliser	**With fertiliser**	**No fertiliser**	**With fertiliser**
Land preparation (slashing)	-	-	90 000	90 000	90 000	90 000
Land preparation (herbicide application)	-	-	50 000	50 000	50 000	50 000
Land preparation (1st ploughing)	120 000	130 000	-	-	-	-
Land preparation (2nd ploughing)	80 000	100 000	-	-	-	-
Maize seed (10 kg)	80 000	80 000	80 000	80 000	80 000	80 000
Ripping (oxen hire)	-	-	100 000	100 000	-	-
Planting	100 000	120 000	100 000	100 000	100 000	100 000
Weeding using hand hoe (twice)	200 000	200 000				
Herbicide application	-	-	50 000	50 000	50 000	50 000
Herbicide (5 litres)	-	-	100 000	100 000	100 000	100 000
Fall army worm spraying (twice)	100 000	100 000	100 000	100 000	100 000	100 000
Insecticide (two bottles)	30 000	30 000	30 000	30 000	30 000	30 000
Harvesting	100 000	100 000	100 000	100 000	100 000	100 000
Threshing	50 000	50 000	50 000	50 000	50 000	50 000
Drying of maize	50 000	50 000	50 000	50 000	50 000	50 000
Fertiliser application (twice)	-	-	-	100 000	-	100 000
Fertiliser – Urea (50 kg)	-	-	-	175 000	-	175 000
Fertiliser – DAP (50 kg)	-	-	-	175 000	-	175 000
Digging of planting basins[a]	-	-	-	-	350 000	350 000
Preparing of planting basins[b]	-	-	-	-	150 000	150 000
Tree seedlings (1 800) [a]	540 000	-	-	-	-	-
Cutting back of trees (thrice)[c]	240 000	-	-	-	-	-
Ploughing biomass into soil (thrice) [c]	360 000	-	-	-	-	-
Planting of trees [a]	120 000	-	-	-	-	-
Weeding of trees (thrice) [c]	300 000	-	-	-	-	-
Beating up (replanting of trees) [a]	50 000	-	-	-	-	-
Total	**2 520 000**	**960 000**	**900 000**	**1 350 000**	**1 300 000**	**1 600 000**

Notes: [a] Establishment costs incurred in 2018 only; [b] Maintenance costs incurred in 2019 only; [c] Frequency of activity/ expenditure was thrice in 2018 and twice in 2019. Cost of conventional farming and ripping remained the same in 2018 and 2019.

1US$ = 3 536 to 3 690/- Ugx (from November 2018 to May 2021), Ugx = Uganda shillings

3. Results and discussion

3.1 General yield assessment

The different treatments assessed revealed variability in maize response to the various climate-smart technologies (Figure 2). Over the two years, experimental plots in which *Gliricidia* was used as green manure produced the highest mean yield per acre (3 052.7 ± 122.8 kg). There were seasonal variations in maize yield over the two planting seasons. This implies that weather patterns could have been different over the two spells. Similarly, seasonal weather effects on crop yield have also been reported in previous studies (Yen & Hong 2021). Plots on which maize was planted in rip lines and in permanent planting basins were not significantly different. The control plots recorded the lowest yields (Figure 2).

3.2 Performance of rip-line technology

Maize yield was enhanced significantly across the different locations when sown in ox-drawn rip lines. Thus, the use of rip lines increased maize yield from 1 325.6 ± 34.5 kg/acre to 1 472.4 ± 54.8 kg/acre in 2018 (Table 2). Also, the maize yield increment in 2019 was higher than that of the previous year. Another notable trend was the significant increase in maize yield when planting was accompanied by fertiliser application. There were exceptions for the Lamwo (2018 and 2019) and Pader (2018) districts where fertiliser application did not result in a significant yield increment.

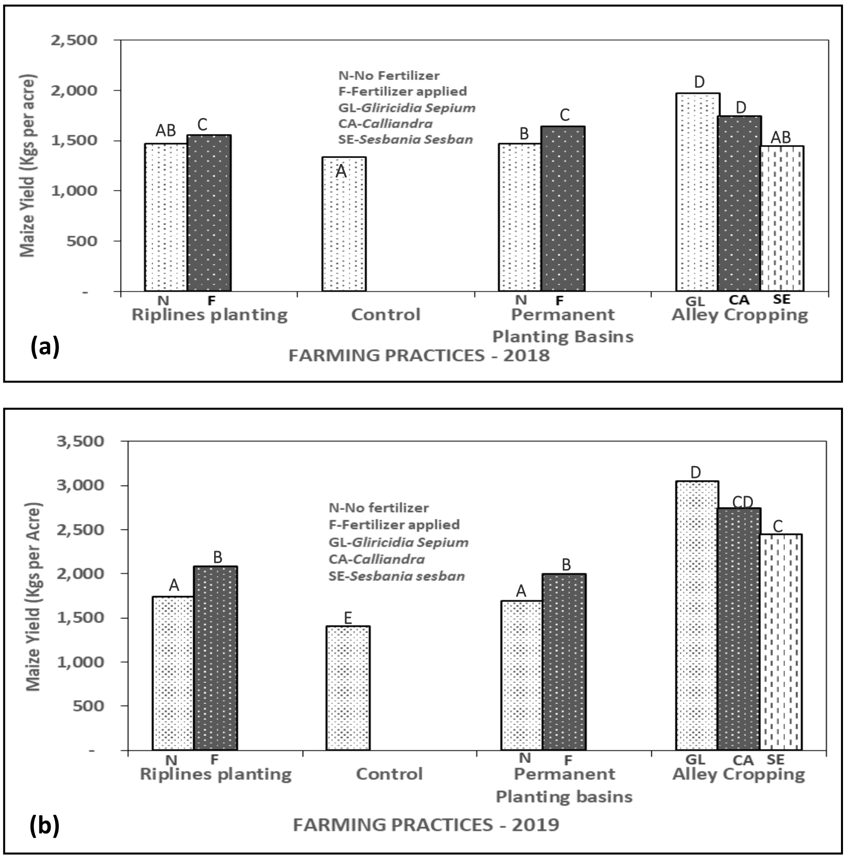

Figure 2: Overall maize yield assessment in 2018 and 2019, with alley cropping, permanent planting basins and ripping

Notes: The values represent the overall mean yield of the different farming practices in 2018 and 2019. Different letters above columns indicate statistical differences between treatments by Tukey's HSD test ($p < 0.05$).

3.2 Performance of rip-line technology

Maize yield was enhanced significantly across the different locations when sown along ox-drawn rip lines. Thus, the use of rip lines increased maize yield from 1 325.6 ± 34.5 kg/acre to 1 472.4 ± 54.8 kg/acre in 2018 (Table 2). The maize yield increment of 2019 also was higher than that of the previous year. Another notable trend was the significant increase in maize yield when planting was accompanied by fertiliser application. There were exceptions for the Lamwo (2018 and 2019) and Pader (2018) districts, where fertiliser application did not result in a significant yield increment.

Table 2: Assessment of rip-line technology across various sites in 2018 and 2019

Year	Location	Ripping without fertiliser	Ripping with fertiliser	Conventional method
		Yield (kg/acre)	**Yield (kg/acre)**	**Yield (kg/acre)**
2018	Lamwo	1 995.7 (1908; 2083)	1 814.3 (1 723; 1 906)	1 555.2 (1 486; 1 624)
	Gulu	1 128.1 (1 053; 1 203)	1 888.9 (1 796; 1 982)	1 022.6 (969; 1 076)
	Pader	1 293.5 (1 232; 1 355)	1 228.8 (1 148; 1 310)	1 176.0 (1 124; 1 229)
	Overall	**1 472.4 (1 418; 1 527)**	**1 644.0 (1 587; 1 701)**	**1 325.6 (1 291; 1 360)**
2019	Lamwo	2 764.5 (2688; 2 841)	2 129.4 (2 052; 2 207)	2 100.1 (2 013; 2 187)
	Gulu	993.4 (945; 1 042)	1 782.8 (1 723; 1 842)	465.4 (434; 496)
	Pader	1 640.2 (1 562; 1 718)	2 511.4 (2 417; 2 606)	1 461.2 (1 382; 1 540)
	Overall	**1 799 (1 723; 1 876)**	**2 141 (2 089; 2 193)**	**1 342 (1 270; 1 415)**

Note: Values are mean maize yields with the corresponding minimum and maximum values in brackets to indicate the range of the standard error (SE).

3.3 Performance of permanent planting basins

Similar to rip-line technology, planting maize in permanent planting basins enhanced maize yield in 2018 and 2019. Across the different experimental plots and locations, maize yield was significantly enhanced by planting basins along with fertiliser application, as indicated in Table 3.

Table 3: On-farm evaluation of permanent planting basins

Year	Location	Planting basins without fertiliser	Planting basins with fertiliser	Conventional method
		Yield (kg/acre)	**Yield (kg/acre)**	**Yield (kg/acre)**
2018	Lamwo	1 814.3 (1 723; 1 906)	2 055.4 (1 969; 2 141)	1 555.2 (1 486; 1 624)
	Gulu	1 206.8 (1 166; 1 247)	1 376.8 (1 355; 1 399)	1 022.6 (969; 1 076)
	Pader	1 389.7 (1 346; 1 433)	1 496.0 (1 461; 1 531)	1 176.0 (1 124; 1 229)
	Overall	**1 470.3 (1 428; 1 513)**	**1 642.7 (1 602; 1 684)**	**1 325.6 (1 291; 1 360)**
2019	Lamwo	2 303.1 (2 259; 2 347)	3 130.6 (3 111; 3 151)	2 100.1 (2 013; 2 187)
	Gulu	1 618.3 (1 577; 1 659)	1 366.2 (1 345; 1 387)	465.4 (434; 496)
	Pader	1 476.2 (1 454; 1 499)	1 487.0 (1 468; 1 506)	1 461.2 (1 382; 1 540)
	Overall	**1 799.2 (1 749; 1 849)**	**1 994.6 (1 922; 2 067)**	**1 342 (1 270; 1 415)**

Note: Values are mean maize yields, with the corresponding minimum and maximum values in brackets to indicate the range of the standard error.

Regarding the two MT practices evaluated, similar studies by Haggblade and Tembo (2003) and Githongo *et al*. (2021) also revealed greater yields than from the control experiment (see Tables 2, 3 and 4); yield gains were even greater with fertiliser application. Yield benefits brought about by MT are mainly attributed to improvements in water infiltration, soil moisture, soil porosity and buildup of soil organic matter (Arslan *et al*. 2014; Githongo *et al*. 2021). This probably explains the higher yields reported for ripping and planting basins. A similar trend was observed in a study conducted by Mubiru *et al*. (2017), in which maize yield was enhanced by planting basins and rip lines in Nakasongola district, Uganda. The only disparity is the reverse superiority in performance where permanent planting basins gave higher yields than rip lines. This could be due to the better moisture retention ability of the planting basins.

In this study, fertiliser use in the MT plots was found to enhance maize yield at all locations except in Lamwo (2018/2019), Gulu (2019) and Pader (2018/2019) districts (Tables 2 and 3). In contrast, fertiliser application in Lamwo and Gulu resulted in a decline in yield, whereas only a negligible effect of fertiliser use was recorded in Pader. A related outcome was observed in a study conducted by Njoroge *et al*. (2018) in western Kenya, where the application of standard N, P and K fertiliser resulted in a yield decline of 0.7 t ha^{-1} below the control in relatively fertile areas. In comparison to other areas (Table 2), Lamwo had the most fertile soils based on the high yields observed from the control plots (2 100 kg/acre). This phenomenon can be explained by the fact that unnecessary or excessive fertiliser application can result in low nutrient-use efficiency (Tilman *et al*. 2011; Wang *et al*. 2022), and does not guarantee yield gains. This probably means that the experimental plots in Lamwo had adequate levels of nutrients, implying that fertiliser application might have resulted either in a surplus amount of soil N (in the form of nitrate) and P, or caused deficiencies in other nutrients (Okalebo *et al*. 2002; Rahman & Zhang 2018).

Nonetheless, this anomaly was reversed because, according to Yang *et al*. (2018), maize production can be enhanced with reduced fertiliser application along with green manure application. This means that integrating alley cropping into fertiliser application in MT practices could be a possible remedy for addressing some incidences of poor fertiliser response. Since different locations have different fertility levels, it is important to identify the most suitable fertiliser intervention that fits each location to enable farmers to make well-informed decisions on fertiliser use.

Other factors responsible for reduced fertiliser efficiency include poor seedbed preparation, unbalanced fertiliser application, weed infestation, inadequate irrigation, inadequate plant population and insect attacks (FAO 1981; Aryal *et al*. 2021). The execution of MT practices requires weed suppression through soil cover by crop residues (or cover crops) and herbicide application. However, throughout 2019, relentless heavy rains made it very difficult to effectively manage weeds through herbicide application, resulting in weed infestation in some experimental plots. This therefore suggests that weed infestation possibly could have contributed to reduced fertiliser efficiency in Lamwo, Gulu and Pader.

3.4 On-station evaluation of alley cropping

The highest yield obtained was 3 052.7 ± 122.8 (kg/acre) in 2019 from experimental plots on which *Gliricidia* was incorporated as green manure (Figure 3). The performance of *Calliandra* was not statistically different from the control treatment, at ≤ 0.05. The lowest maize yield was obtained with *Sesbania*. In fact, trial plots treated with *Sesbania* as green manure over the two years got lower yields than the control (Figures 3a and 3c). A possible explanation for this anomaly is that the *Sesbania* trees may have competed with the maize crop for water and nutrients The amount of soil nitrogen (soil N) recorded after harvest in both planting seasons was highest in plots containing *Calliandra* and *Gliricidia* (not a statistically significant difference between them), followed by the control and *Sesbania* plots in descending order (Figures 3b and 3d).

Leguminous alley tree species are mainly domesticated for their ability to fix, accumulate and supply large amounts of N, while non-legumes are mainly used to prevent soil erosion, trap N and reduce its leaching into the water table (Jangir *et al*. 2022). Among the benefits of alley cropping improvements in soil fertility and increasing the stability of N supply (Hombegowda *et al*. 2022). Thus, the amount of soil nitrogen fixation observed in the current study (see Figure 3) is in line with other findings that the application of organic substrates can increase total soil N (Aryal *et al*. 2021; Jangir *et al*. 2022).

3.5 Yield advantage of selected farming practices

This study shows that the farming practices investigated have a positive effect on crop yield, except for alley cropping using *Sesbania*. Actually, the use of *Sesbania* as green manure resulted in a decline in crop yield over the two planting seasons evaluated, although not significantly in 2019 (Table 4). The highest yield advantage was observed for experimental plots on which maize was planted along rip lines in 2019. The yield advantage for planting basin and rip-line technology was increased by 30.0% to 54.3% through fertiliser application (Table 4).

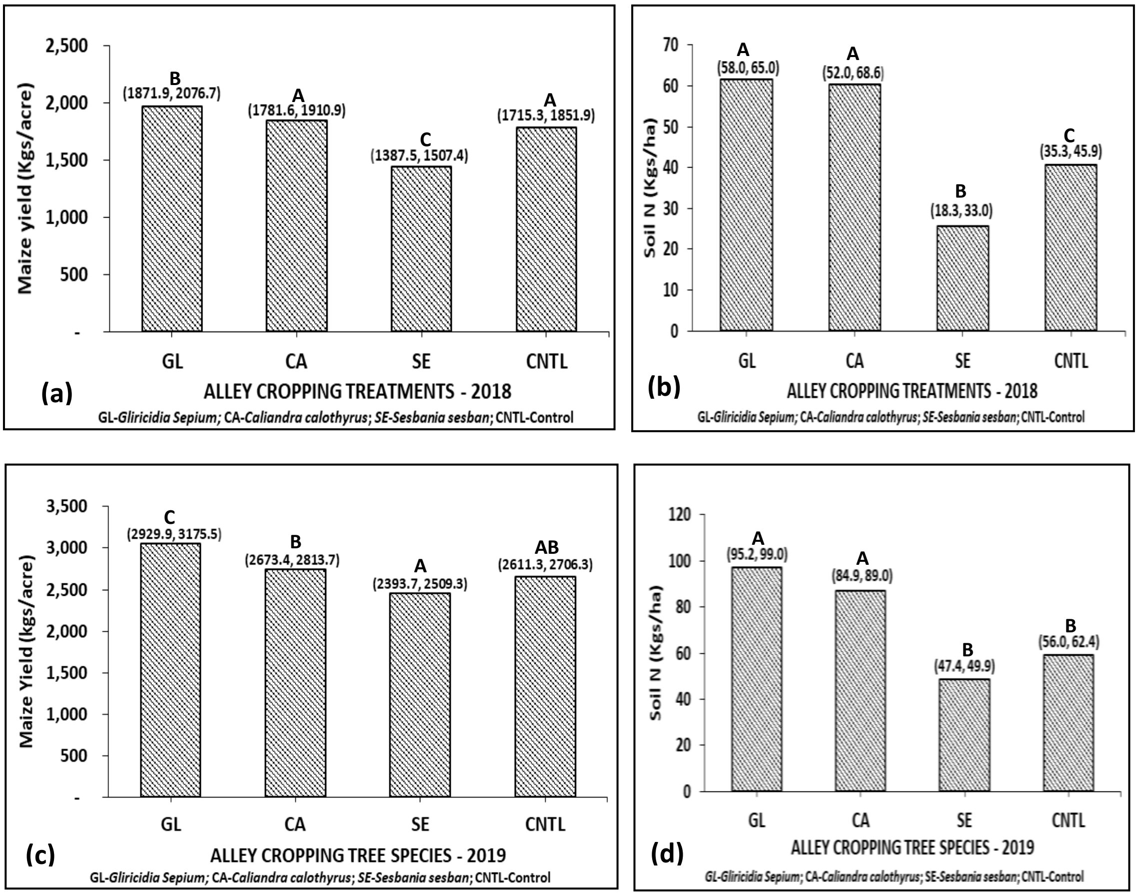

Figure 3: Maize yield under alley treatments [(a) and (c)], and soil N for various alley treatments after harvest [(b) and (d)]

Note: Values within columns are respective means with the corresponding minimum and maximum values in brackets to indicate the range of the SE. Different letters above columns indicate statistical differences between treatments by Tukey's HSD test ($p < 0.05$).

Table 4: Assessment of yield advantage amid ripping, planting basins and alley cropping

Year	Farming practice/treatment	Yield increment attributed to CSA practice (kg/acre)	Increment due to fertiliser use (kg/acre)	Overall yield advantage (kg/acre)
2018	Rip-line technology	146.9 ± 55.6 (2.64)	171.6	318.5 ± 64.3 (4.95)
	Permanent planting basins	144.7 ± 50.2 (2.88)	172.5	317.2 ± 46.3 (6.84)
	Alley cropping – *Gliricidia*	336.4 ± 103.6 (3.24)	N/A	336.4 ± 103.6 (3.24)
	Alley cropping – *Calliandra*	62.7 ± 93.4 (0.59)	N/A	62.7 ± 93.4 (0.59)
	Alley cropping – *Sesbania*	-336.1 ± 98.1 (-3.19)	N/A	-336.1 ± 98.1 (-3.19)
2019	Rip-line technology	457.1 ± 57.6 (7.93)	341.8	799.0 ± 77.5 (10.3)
	Permanent planting basins	456.7 ± 83.5 (5.47)	195.6	652.4 ± 58.4 (11.17)
	Alley cropping – *Gliricidia*	437.2 ± 135.6 (3.22)	N/A	437.2 ± 135.6 (3.22)
	Alley cropping – *Calliandra*	156.3 ± 95.0 (1.64)	N/A	156.3 ± 95.0 (1.64)
	Alley cropping – *Sesbania*	-71.2 ± 73.5 (-0.97)	N/A	-71.2 ± 73.5 (-0.97)

Notes: Data are mean values ± standard error. Figures in brackets are $t_{\mathbf{stats}}$, where $t_{\mathbf{crit.\ (2018)}} = 1.98$ and $t_{\mathbf{crit.\ (2019)}} = 1.98$ for rip lines and planting basins, and 2.09 for alley cropping.

3.6 Return on investment for CSA practices

The study revealed that return(s) on investment was directly related to the various farming practices examined. The use of planting basins, rip lines and alley cropping proved to be economically beneficial. In addition, the use of fertiliser gave higher yields, but significantly reduced net returns for the planting basins and rip-line technology (Table 5). This is attributed to the costs associated with fertiliser application, meaning that the additional yield was not adequate to compensate for the cost of fertiliser and labour for its application. It also implies that fertiliser application may not be necessary where soil nutrients are adequate.

Profitability rose significantly from 2018 to 2019 (Table 5), and this can be explained by two factors. Firstly, there were glaring seasonal differences in maize grain yield due to the higher precipitation in 2019 than in 2018. The other reason is that capital investments dropped in the second year. For instance, establishment costs for alley trees in 2018 were not incurred in 2019. Similarly, planting basins that were established in 2018 were not re-established but maintained in 2019. It therefore is profitable to keep trees and permanent planting basins (PPB) over several seasons.

Table 5: Economic analysis of maize cultivation as influenced by farming practice

Year	**CSA practice/treatment**	**Yield (kgs)**	**Cost of CSA practice ('000 Ugx)**	**Gross return ('000 Ugx)**	**Net return ('000 Ugx)**	**BCR**
2018	Ripping without fertiliser	1 472	900	1 472	572	1.64
	Ripping with fertiliser	1 644	1 350	1 644	294	1.22
	PPB without fertiliser	1 470	1 150	1 470	220	1.28
	PPB with fertiliser	1 643	1 600	1 643	43	1.03
	Alley cropping – *Gliricidia*	1 974	2 240	1 974	-266	0.88
	Alley cropping – *Calliandra*	1 846	2 240	1 846	-394	0.82
	Alley cropping – *Sesbania*	1 447	2 240	1 447	-793	0.65
	Conventional farming	1 326	960	1 326	366	1.38
2019	Ripping without fertiliser	1 761	900	1 761	861	1.96
	Ripping with fertiliser	2 134	1 350	2 134	784	1.58
	PPB without fertiliser	1 799	950	1 799	749	1.71
	PPB with fertiliser	1 942	1 400	1 942	542	1.39
	Alley cropping – *Gliricidia*	3 020	1 510	3 021	1 511	2.00
	Alley cropping – *Calliandra*	2 713	1 510	2 713	1 203	1.80
	Alley cropping – *Sesbania*	2 427	1 510	2 427	917	1.61
	Conventional farming	1 314	960	1 314	354	1.37
Overall (cumulative)	Ripping without fertiliser	3 233	1 800	3 233	1 433	1.80
	Ripping with fertiliser	3 778	2 700	3 778	1 078	1.40
	PPB without fertiliser	3 269	2 100	3 269	969	1.56
	PPB with fertiliser	3 585	3 000	3 585	585	1.20
	Alley cropping – *Gliricidia*	4 995	3 750	4 995	1 245	1.33
	Alley cropping – *Calliandra*	4 560	3 750	4 560	810	1.22
	Alley cropping – *Sesbania*	3 874	3 750	3 874	124	1.03
	Conventional farming	2 640	1 920	2 640	720	1.37

Notes: BCR - Benefit:cost ratio; prices are shown in thousands of Uganda shillings (Ugx)

4. Conclusions and recommendations

The study shows that permanent planting basins, rip lines and alley cropping with *Gliricidia* enhanced the yield in maize production and were profitable CSA practices under demonstration plots. Even though these technologies were found to be beneficial, they still tend to have different opportunities and challenges. For instance, MT has the potential to ease the labour demand of weeding on women and children (due to herbicide application), but the construction of planting basins is quite laborious. Ripping is a complementary technology, since the ripper is easily attached to existing ox ploughs, but access to the ripper may be limited. Alley cropping is also complementary, as tree biomass can be conventionally ploughed into the soil during land preparation or weeding, or utilised for fuelwood, but it requires intensive management. These challenges can be addressed by supportive services and the policy environment. This calls for greater collaboration between governments, NGOs, civil society and the private sector to provide farmers with access to extension services, incentives and finance. To reinforce this collaboration, it is necessary for all the actors to implement CSA in a coordinated manner.

From an economic viewpoint, more site-specific studies on CSA interventions need to be conducted. Such studies may involve the integrating of MT practices with alley cropping for green manure, making it possible to delineate locations that require intensive inorganic fertiliser or organic substrate amendments from those that may need minimum CSA interventions. This also suggests that soil nutrient analysis should be a requirement before fertiliser application is recommended. A practical approach would be to ensure that farmers have access to user-friendly soil fertility test kits.

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