Assessment of a Climate-smart Cropping Combination for Integrated Crop and Livestock Production System

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ABSTRACT

Aims: To investigate sustainable climate-smart cropping combinations for integrated production of crops and livestock.
Study Design: The mother baby trial design was used. The mother trial being an on-station experiment and the on-farm being baby trials. The experiment was arranged as a split plot design. The main plots were 3 types of soil amendments; cattle manure, fertilizer and a control. The subplots were eight (8) crop combinations, arising from velvet bean, cowpea, rhodes grass and ryegrass.
Place and Duration of Study: The on-station field experiment was located at Liempe farm of the University of Zambia, in Chongwe district. The on-farm experiments were laid in Mazabuka and Chibombo districts of Zambia for two consecutive seasons, 2016/17 and 2017/18 cropping seasons.

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Methodology: The cropping combination responses were measured based on variable performance of maize test-crop. The 'soil amendments type' and 'crop combination' performance were evaluated using analysis of variance. Means were separated using Fisher protected Least Significant Difference (LSD) at α = 0.05. Principal component analysis (PCA), was also undertaken to further understand responses among crop combinations. Farmers reactions arising from experimental implementation was qualitatively analysed using content analysis.

Results: Significant differences (P = .05) across cropping combinations on measured variables (for maize test crop) were exhibited among soil amendments type at an on-station trial during the 2017/18 season. Fertilizer soil amendment type was the best performer followed by manure and the control. Significant differences (P = .05) were also obtained among crop combinations across soil amendment type in all experimental sites. Crop combinations with velvet bean performed better than others. Qualitative grass inspection showed that rhodes grass was a better performer than rye grass.

Conclusion: Maize grown in combination with legumes particularly velvet beans and rhodes grass are a viable option as a smallholder farming practice in a changing climate.

1. INTRODUCTION

Conservation Agriculture (CA) is among the most prominently promoted climate smart agriculture practices that have the potential to contribute to the multiple benefits mentioned within the context of the three CA principles [1]. These being minimum soil disturbance, rotations and intercropping and residue retention [2] with crop residues being used as supplementary feed for livestock. Integrated crop-livestock systems, if well managed, are recognized as one of the most promising means of adapting to climate change, while mitigating the contributions of crop and livestock production to greenhouse gas emissions [3]. There are a number of climate smart agricultural practices that have been singly proven to be effective in delivering benefits such as improved crop yields, livestock productivity, climate change adaptation and mitigation [4]. For example, agroforestry practices such as integration of legumes (crops and trees like velvet bean, and *Sesbania sesban,* respectively) with cereals sustainably improves soil fertility [5].

To improve productivity of both crops and livestock on smallholder farms, there is need for development of integrated farming systems that promote sustainable use of locally available resources. This can address impediments associated with increasing land degradation and poor productivity of livestock and rural farming enterprises as a result of climate change vulnerabilities. Improved agricultural productivity will go a long way in facilitating household food security and improve income generation while at the same time mitigating challenges associated with increased soil degradation and climate change. For instance, owing to climate variability, latest findings in sub-Saharan Africa have shown that the rainfall distribution pattern has become increasingly unpredictable affecting both crop and animal productivity [6,7]. Lately poor crop yield have been realised in mostly southern part of the Zambia, Mazabuka and Chibombo inclusive. Therefore on-farm and on-station research trials were carried out in Zambia to investigate sustainable climate-smart cropping combinations for integrated production of crops and livestock.

2. MATERIALS AND METHODS

2.1 Description of Study Sites

The on-station field experiment, conducted during 2016/17 and 2017/18 cropping season, was located at Liempe farm (15.357°S; 28.457°E) of the University of Zambia (UNZA), in Chongwe district. The farm is classified as experiencing a humid subtropical climate [8] with unimodal rainfall ranging from 800 to 1000 mm per annum and is located about 20 km from the University main campus.

On-farm trials were conducted during 2016/17 and 2017/18 cropping in Mazabuka (18.8613°S, 27.7491°E) and Chibombo (14.6554°S, 28.0889°E) districts of Zambia. The 12 selected farmer sites (farms) in this study were chosen based on their previous participation under conservation farming. The farmers gave consent to use their field for experimentation.

2.2 Experimental Design and Treatments

The trial was laid according to a mother – baby trial according to a method of Buah [9]. The

Mother (On-station) site was the UNZA site at Liempe while the Baby (On-farm) were 12 farmer sites located in Chibombo and Mazabuka districts of Zambia. The experiment was arranged as a split plot design. The main plots were three (3) types of soil amendments namely; cattle manure, fertilizer and a control (no soil amendment). The subplots were eight (8) crop combinations namely; i) maize/cowpea +ryegrass,ii) maize/cowpea + rhodes grass, iii) maize/cowpea, iv) maize/velvet bean + rhodes grass, v) maize/velvet bean, vi) maize/velvet bean + ryegrass, vii) maize/cowpea +velvet bean and viii) maize only (M). Maize was used in all combinations as a test crop. Varieties (type) of maize, cowpea, velvet bean planted were SC 513, musandile and black velvet respectively. Ryegrass and rhodes grass were obtained from Hygrotech seed Limited and Klein Karoo company, respectively. Each crop was planted in a row and alternated with another type where appropriate. Standard instructional planting procedures were followed for each crop combination.

2.3 Management of Experimental Plots

The herbicide glyphosate, a non-selective herbicide, was applied in order to clear the vegetation and weeds which were overgrown all experimental sites**.** Thereafter, experimental sub-plots of 100 m^2 (10 x 10 m) were marked out. Four (4) weeks after application of the herbicide, rip lines using hand holes were made to open up the stations where the crop would be planted. Cattle manure was then applied by hand at a rate of 10 tons per hectare to the main plots intended for manure treatment. Planting in all the experimental plots was done four weeks after manure application. The crop combinations were inter-planted in each plot.

The fertilizer application treatment was done by hand. It comprised 200 Kg/ha "D" compound and 200kg/ha Urea was applied as basal and top dressing, respectively. This application rate represented the standard recommendation for maize production under small holder farming conditions in Zambia. The fertilizer rate of 200 kg/ha basal dressing contained 20 kgN/ha, 17.2 kgP/ha and16.6 kgK/ha; while the rate of 200 kg/ha top dressing contained 92 kgN/ha. The pests were controlled by spraying the crop with monocrotophos. The control main plots did not receive any soil amendment.

2.4 Qualitative and Quantitative Trial Assessment

Assessment of the trial was done both qualitatively and quantitatively. Qualitative assessment involved visual observation of the trials, taking note of key differences among and within crop combinations. In addition, qualitative analysis considered farmers' views on experimental trial implementation and execution of the experiment. Quantitative assessment involved analysis and interpretation of measured variables on a test crop (maize).Variables measured on maize test-crop during vegetative phase were average leaf area (mm^2), chlorophyll content index (CCI) measured with leaf area meter and chlorophyll meter, respectively. Plant height (mm) was measured using a 1 m ruler. At harvest, yield (kg/ ha), termite damage, 100 seed weight (g), cob diameter (cm) and cob length (cm), were measured. Termite damage was taken as the direct count at harvest and as the number of maize stems which were cut at the base by termites.

As earlier stated maize (SC 513) was used as a test crop to assess the performance for the soil amendment types (main plots) and crop combinations (sub-plots). Assessment was conducted during two seasons, namely 2016/17 and 2017/18 growing season for both on-station and on-farm trials. In both seasons, initial first round of crop (vegetative) evaluation was done 30 days after planting. However, the second round of evaluation was only conducted in the 2017/18 growing season as the first season's 2016/17 trial was unable to reach harvestable stage (rainfall ended early).

2.5 Data Analysis

The 'soil amendments type' and 'crop combination' performance were evaluated using analysis of variance (ANOVA). Means were separated using Fisher protected Least Significant Difference (LSD) at α = 0.05. A multivariate analysis, Principal component analysis (PCA), was also undertaken to generate a PCA plot for further analysis of crop combination with mean performance for each variable pooled across on-station and on farm. All the quantitative analyses were performed using GenStat [10]. Farmers responses/ reactions arising from implementation of the trial was qualitatively analysed using content analysis [11].

3. RESULTS

3.1 Analysis of Soil Amendment and Crop Combinations

Generally, the on-farm farmer participation in the first season (2016/17) trial was substandard. Equally, the on-station trial did not reach harvestable stage as the rains ended before harvestable stage was reached.

In the second experimental season 2017/18, significant differences (P = .05) were obtained among measured variables for both soil amendments and crop combination treatments from the mother trial at Liempe farm (Table 1).

3.2 Measured Variables on Each Soil Amendment Type Across Crop Combinations

Among the soil amendments, fertiliser application performed better than the control and manure application across crop combinations on all measured variables (Table 2). Manure application also performed better than the control across crop combinations on all measured variables.

Table 1. Analysis of mean squares on soil amendment and crop combinations on measured variables on the maize test crop evaluated at Liempe farm, UNZA during the 2017/18 cropping season

SOV	df	CCI	CL	CD	100SW	LAI	PHT	TA	Yield
S	2	4619.5 ***	29.1	0.5	175.2**	14138.4 **	31037.3 ***	11611	8311590 *
Error	6	7	5.8	0.7	8.8	320.6	44.1	3279	828404
C	7	40.5 ***	3.7	0.2	9.7	205.5	65.5	5561 *	5668883 ***
S X C	14	16.2 **	2	0.3	2.3	58.8	16.9 ***	1543	271929
Error	42	5.2	3.7	0.3	7	55.4	3.2 ***	2012	362935

*, **, ***- F-test significant at P = .05, P = .01 and P = .001 respectively, SOV - Source of variation, S - Soil amendments, C - Crop combinations, CCI - Chlorophyll Concentration Index, 100 SW - Hundred seed weight (g); CD - Cob diameter (cm); CL - Cob Length (cm); TA - Termites attack; LA - average leaf area (cm^2); PH - Plant height (cm). LSD - Fisher protected least significant difference

Table 2. Mean of measured variables on each soil amendment type across crop combinations evaluated at Liempe farm during the 2017/18 cropping season

S. A	CCI	CL	CD	100 SW	LA	PH	TA	Yield
Control	13.14	10.79	6.51	26.65	103.75	52.65	68.9	716
Manure	22.97	11.32	6.66	28.96	109.96	105.51	86.8	1062
Fertilizer	40.53	12.9	6.8	32.03	148.55	121.33	43	1863
LSD(α=0.05)	2.12	1.93		2.38	14.35	5.32		729.5

S. A - Soil amendment, CCI - Chlorophyll Concentration Index, 100 SW - Hundred seed weight (g); CD - Cob diameter (cm); CL - Cob Length (cm); TA - Termites attack; LA - average leaf area (cm^2); PH - Plant height (cm); Control – no amendment was done; LSD - Fisher protected least significant difference

Table 3. Mean of measured variables for each crop combinations across soil amendments evaluated at Liempe farm, UNZA during the 2017/18 cropping season

Crop combination	CCI	CL	C D	100 SW	LA	PH	TA	Yield
Cowpea	23.38	11.89	6.71	28.12	115.86	91.46	72.1	1090
Cowpea + Rhodes	23.14	11.32	6.47	27.86	117.84	90.2	64.2	693
Cowpea + Rye	26.36	11.8	6.7	29.98	118.49	90.64	87.7	492
Cowpea + Velvet	29.41	11.68	6.57	28.47	131.22	97.54	48.4	2924
Velvet	26.55	11.12	6.61	28.94	120.55	94.6	22.4	1261
Velvet + Rhodes	25.84	10.8	6.59	29.36	120.48	95.2	59.4	1261
Velvet + Rye	26.13	12.96	6.99	30.51	123.3	94.76	70.3	1530
Control	23.57	11.8	6.64	30.48	118.26	90.92	105.3	458
LSD (α=0.05)	2.18		0.54		7.08	1.7	42.71	573.1

CCI - Chlorophyll Concentration Index, 100 SW - Hundred seed weight (g); CD - Cob diameter (cm); CL - Cob Length (cm); TA - Termites attack; LA - average leaf area (cm^2); PH - Plant height (cm). Control - Only test crop was grown. LSD - Fisher protected least significant difference

Table 4. Analysis of mean squares of soil amendments and crop combinations on measured variables on the maize test crop evaluated on farm (Mazabuka and Chibombo), during the 2017/18 cropping season

SOV	df	100 SW	Yield	C D	CL	TA	CCI	LA	PH
S	1	33.6	8142029	0.03	15.8	0.28	6912.53	101539.3	3424.2
Error	1	20.9	6041224	0.03	4.3	3.78	667.2	53565.1	675.1
C	7	11.1	841097*	0.3	3.3***	27.6***	26.8*	2642.4***	216.2**
S x C	7	6.2	353249	0.1	1.3*	5.5	3.7	659.5	19.4
Error	14	9.8	271518	0.1	0.5	3.85	8.7	264.4	38.7

*, **, *** - F-test significant at P = .05, P = .01 and P = .001 respectively. S - Soil amendment, C - Crop combination, 100 SW (g) - Hundred seed weight (g); CD - Cob diameter (cm); CL - Cob Length (cm); TA - Termites attack; CCI - Chlorophyll Concentration Index, LA - Average leaf area (cm^2); PH - Plant height (cm)

3.3 Variables for Each Crop Combinations across Soil Amendments

Comparisons among 'crop combinations' with regards to variable responses on the test crop (maize) showed that combinations with velvet bean performed better than other non-velvet bean combination across all 'soil amendments type'(Table 3).

3.4 Soil Amendments and Crop Combinations on Measured Variables on the Maize Test Crop

With on farm, significant differences were however only observed on cropping combinations across soil amendments on all measured variables (Tables 4 and 5). Similarly, velvet bean combinations performed better than non-velvet bean combination with regards to variable response on all measured parameters (Table 5).

3.5 Principled Component Analysis for on-Farm and on-Station Experimental Trials

The multivariate analysis using PCA, performed on pooled mean on all measured variable for on-farm and on-station experimental trials for 2017/18 equally showed velvet bean combinations as better performers (cluster C) (Fig. 1).

3.6 Field Qualitative Assessment

Generally the farmers were reluctant to participate in the implementation of first experimental season (2016/17) as compared to the second experimental season (2017/18). Qualitative assessment of the crop combinations performance on test crop (maize) revealed that crop combinations with velvet plots appeared healthier that others during the vegetative phase. Further, visual inspection of grasses in crop combinations showed that rhodes grass performed better than ryegrass at both on-farm and on-station experimental sites. Ryegrass exhibited serious signs of wilting and eventually died in some plots during the 3- week dry and hot (average 31.5°C) period of January 2018 which was experienced in all experimental site. Visual appearance of soils in velvet bean plots compared to other plots during the 3-week dry spell showed that crop combination with velvet was wetter than others.

4. DISCUSSION

4.1 Farmers Participation Soil Amendment and Crop Combinations Experiment

The farmers were reluctant to participate in the first experimental season (2016/17) on the soil amendment and crop combinations study. This coincided with previous revelations, that found out that new research approaches are unlikely to be as pervasive to farmers as the old and common approaches [12]. Emphasis on importance of these trial were recommunicated to farmers and that contributed to an improved farmer participation in the second experimental season (2017/18).

With on farm, second experimental season (2017/18 cropping season), only farmers assigned with Fertilizer and Manure soil amendments type implemented the trial to completion except one manure farmer who cited inadequate manure at his farm as the reason for abandoning. This scenario is in line with what was previously unveiled that farmers tend to be reluctant to adopt practices or technologies

Table 5. Mean of measured variables on crop combination type across soil amendments evaluated on farm (Mazabuka and Chibombo), during the 2017/18 cropping season

Crop combination	Yield	CL	CD	TA	100 SW	CCI	LAI	PH
Control	615	10.5	7.13	9	27.68	23.46	128	65.35
cowpea + Rye	1450	10.53	7.08	4.75	29.17	26.64	151.5	75.5
cowpea + Rhodes	1162	10.85	7.08	4.25	27.64	26.3	153.9	77.5
Cowpea only	1293	10.33	6.93	5.25	27.5	25.9	144.8	76.69
Velvet + Cowpea	2274	11.72	7.58	1	28.81	31.24	210.7	88.2
Velvet + Rhodes	1348	10.8	6.93	2	29.66	30.16	185.9	85.67
Velvet + Rye	1427	12.33	7.23	2.5	30.84	27.08	158.8	85.07
Velvet only	1535	12.72	7.63	1.5	32.14	29.65	169.2	81.8
LSD (α=0.05)	790.3	1.03	0.45	2.98	4.75	4.46	24.66	8.93

CCI - Chlorophyll Concentration Index, 100 SW - Hundred seed weight (g); CD - Cob diameter (cm); CL - Cob Length (cm); TA - Termites attack; LA - average leaf area (cm^2); PH - Plant height (cm); Control - Only test crop was grown; LSD - Fisher protected least significant difference
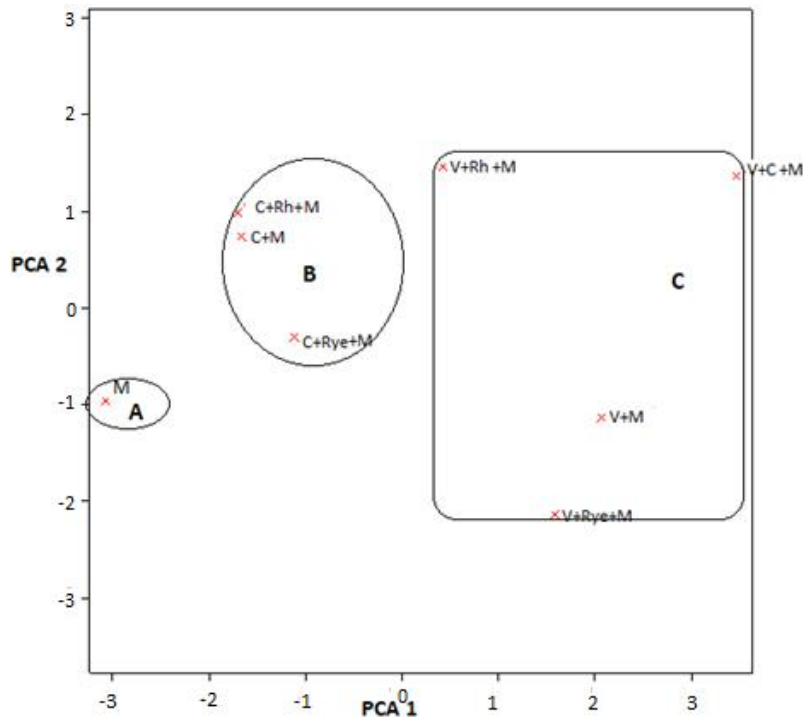

Fig. 1. Principle component analysis plot exhibiting performance of crop combinations. PCA 1 and 2 explain variation of 68% and 22% respectively. Cluster A, B and C shows crop combinations which exhibited similar performance for all mean measured variables across on-station and on farm

M - Maize, C - Cowpea, Rh - Rhodes grass, Rye - Ryegrass, V - Velvet bean

which seems unbeneficial or unprofitable to them [13,14]. Indeed, farmers when interrogated confirmed that the poor vegetative performance of the maize test crop in control plots, meant that they were likely to have poor maize yield in control plots and hence the reason for abandoning. Farmers who participated in this study expected to benefit from the maize grain once all the essential data was collected.

4.2 Performance of Cropping Combinations

The mean superior performance of velvet bean crop combinations (Tables 3 and 5; Fig 1) for all measured variables for both on station and on farm could be attributed to velvet resilient agronomic attributes to harsh condition rather than soil fertility build up as soil tests (Data not

shown) did not confirm that. A severe 3-week January-drought (2017/18 cropping season) environmental conditions, at experimental sites with mean average temperatures of 31.5°C could have caused poor performance of non-velvet crop combinations. Experimental maize in plots with velvet as one of the combiners demonstrated the ability to grow vigorously with reasonable ground cover even under the hard conditions which prevailed in January 2018. Implying that velvet bean has the capability to reduce the impact of drought and heat stress on maize crop. Analysis of velvet bean combination plots (Cluster C) on a PCA plot exhibited similar but better performance than non-velvet bean combination plots (Fig. 1). In fact, Buckles [15], described velvet bean as a crop of wide adaptability. It has been previously reported that appropriate crop combinations can help buffer the effects of erratic rainfall and higher temperatures [16].

The qualitative observation of rhodes grass being a better performer than ryegrass implies that rhodes grass performs better in harsher environment than rye grass. This is supported by previous work which suggested that unlike rhodes grass, ryegrass does not perform well in hostile tropical conditions [17]. The observation of fewer maize being attacked by termites in crop combinations with velvet may imply that soils in velvet bean plots were relatively wetter. Visual appearance of soils in velvet bean plots compared to other plots confirmed that they were indeed wet. Previous studies [18] have shown that wet soils are less prone to termite attack implying that maize yield losses as a result of termite attack are expected to be higher in drought prone areas.

5. CONCLUSION

Based on this study and with regards to conservation agriculture the best crop combination, therefore, should include rhodes grass and velvet bean. Velvet beans enhances soil fertility and it could also be fed to animals. Similarly, rhodes grass could be fed to animals while maize could be used for human consumption as well as in feed ration formulations. These combinations could help farmers to cushion themselves against unpredictable weather regardless of whether they apply fertilizer or manure to their fields. It can be concluded that maize grown in combination with legumes particularly velvet beans and rhodes grass are a viable option as a

smallholder farming practice in a changing climate. Therefore, as a policy guide in sub-Saharan Africa, it's advisable to recommend and promote the intercropping package of maize, velvet bean and rhodes grass. This can cushion against or minimize maize yield losses in case of adverse weather conditions, in addition to providing animal feed from Rhodes grass and velvet bean.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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