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Effect of Cassava-Legume Intercropping Systems on the Physicochemical Properties of the Soil in Three Agro-Ecological Zones of Sierra Leone

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ABSTRACT

The study aims at evaluating the effects of cassava-legume intercropping systems on major soil nutrients across three agro-ecological zones of the country. The experiment was arranged in a randomized complete block design (RCBD) with three replications. The treatments consisted of four cropping systems (sole cassava, cassava + cowpea, cassava + groundnut, and cassava + soybean).The study shows a general decrease in soil pH by 1.48-9.91% and 4.24-11.375% among the agro-ecological zones and cropping systems respectively. Organic carbon increased by 28.8% in the savannah woodland zone in Makeni but decreased by 9.69% and 40.37% in the rainforest zone in Segbwema and the transitional rainforest zone in Sumbuya respectively. It also decreased by 26.27%, 12.08%, and 0.92% for the sole cassava, cassava-cowpea, and cassava-groundnut systems respectively. It was however observed to increase by 10.97% for the cassava-soybean system in the rainforest zone in Segbwema. The total nitrogen, on the other hand, increased slightly by 1.11-1.73% across the agro-ecological zones and 2.62-10.84% for the cropping systems. Total nitrogen for the sole cassava was however observed to decrease by 14.31%. Available phosphorus decreased by 47.35-59.02% and 36.23-72.89% for the agro-ecological zones and the cropping systems respectively. In addition, exchangeable potassium also decreased by 33.33-38.42% and 25.26-49.985 % for the agro-ecological zones and the cropping systems respectively. In addition, the result shows strong, positive, and significant correlations between pH with organic carbon, pH with total nitrogen, organic carbon, and total nitrogen in the three agro-ecological zones.

INTRODUCTION

The sole production of cassava will impoverish the soil rapidly unless the absorbed or lost nutrients are replenished (Eke-Okoro et al., 1999). For example, an average of 660 kg/ ha, 75 kg/ ha, and 450 kg/ ha of Nitrogen, Phosphorus, and Potassium respectively, have been lost from approximately 200 million hectares of cultivated land in thirty-seven African countries (Smaling et al., 1997) in the last thirty years. As a result of this, the necessity to improve soil fertility through the inclusion of legumes into the cropping systems has therefore become a very important issue in the development policy agenda of most African governments due to the strong linkage between soil fertility and food security on the one hand, and the implications on the livelihood of the population on the other (Mugwe et al., 2011). As a result, crop scientists have recommended the inclusion of leguminous crops into crop production systems as a way to address the problem of declining soil fertility. Several studies have reported the advantages of cassava-legume mixtures, especially in improving the nitrogen content of the soil through the fixation of atmosp heric nitrogen (Aigh, 2007). Kurtz (2006) reported significantly higher values of yield and yield components of cassava intercropped with grain legumes than those of the yield components of sole-cropped cassava. However, although legumes are known to fix nitrogen in the soil, studies have shown that the amount of nitrogen fixed depends on the species of the legume. For example, Peoples et al. (2009) reported that (73 – 354), (168 –208), (72 – 124), (55 – 168), and (40 – 65) kg N ha-1 was fixed into the soil by cowpea, pigeon pea, groundnut, and soybean respectively.

Of the sixteen essential plant nutrients needed for plant growth, development, and reproduction, nitrogen is the most important and the most easily limited or deficient throughout the world, particularly in the tropics (Agbede, 2009). The reason for the inadequate supply of nitrogen is the fact that nitrogen exists in organic form in the soil, which must be mineralized before it is used by plants (Azam, 2002). As such, legumes can convert free atmospheric nitrogen (N_2) into ammonia (NH_3) through the process called biological nitrogen fixation (BNF) with the help of specific bacteria (Rhizobium) which reside in the nodules of legumes. The plants will now thereafter transform it into a usable form of plant nitrogen such as amino acids and proteins.

Despite the potential for cassava-legume intercropping technology in addressing the soil nutrient depletion problems of smallholder farmers in some parts of Africa, this knowledge is lacking among the smallholder farmers in Sierra Leone. To this end, this study was mainly aimed at evaluating the effect of intercropping grain legumes with cassava on the major soil nutrients. It is hypothesized that there is a net decrease in the concentration of soil nutrients after the cultivation of sole cassava than when intercropped with legumes such as cowpea, soybean, and groundnut.

MATERIALS AND METHODS

Study area and soil

The study was conducted between 2015-2017 cropping seasons under rain-fed conditions in three agro-ecological zones namely Sumbuya (N 08.040880 , W 011.4789550) in Bo district representing the transitional rainforest, Makeni (N 08.87200 , W 012.03760) in Bombali district representing the savannah woodland and Segbwema (N 07.99300, W 010.952240) in Kailahun district representing the rainforest region of the country (Figure 1).

Land preparation

The land at the three zones was slashed with a cutlass, burnt, destumped, and dug using a hoe and the plots were laid out using a measuring tape, a garden line, and, pegs.

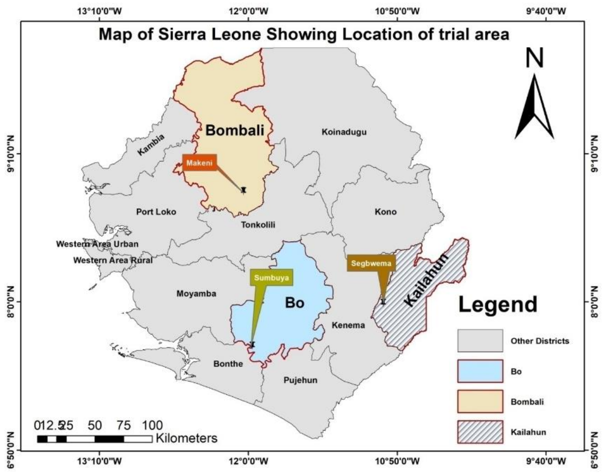

Figure 1 Map of Sierra Leone showing trial sites of the different agro-ecological zones in Sierra Leone

Experimental design, treatments and planting

The experiment was a factorial randomized complete block design with three replications. The treatments consisted of four cropping associations (sole cassava, cassava + cowpea, cassava + groundnut, and cassava + soybean) (Mansaray et al. 2022a). The plot size was 7m x 6 m.

The cassava and the three legumes were planted on a flat land in June of each year. Stem cuttings of about 25 cm long with five nodes were used. Cassava was planted at the spacing of 1 m x 1 m respectively; whilst cowpea and groundnut were planted at the spacing of 50 cm x 20 cm with two seeds per hole for cowpea and one seed per hole for groundnut. On the other hand, soybean was planted at the spacing of 50 cm x 10 cm with two seeds per hole. The legumes were introduced in between the rows of the cassava (Mansaray et al., 2022b).

The cassava variety used was slicass 6 whilst, the cowpea, soybean, and groundnut varieties used were IITA 573k-1-1, Slibean 2, and Slinut 1 respectively. Weeding was done with a hoe at one, three, and six months after planting (Mansaray et al., 2021). Cassava was harvested at 12 months after planting whilst the three legumes were harvested at their respective maturity dates. The haulms of the harvested legumes were returned to the cassava system (Mansaray et al. 2021).

Soil sampling and laboratory analysis

Prior to planting, initial soil samples were collected at each of the three agro-ecological zones. In each zone, ten core soil samples from the topsoil (0- 20 cm) depth were collected in a "W" shaped design and mixed to form a composite sample. Additional soil samples were also collected per treatment at the harvesting stage of the cassava. The samples were air-dried, crushed, and sieve through a 2 mm sieve before analysis for chemical and physical properties using standard laboratory procedures. The soil properties determined were soil pH, total nitrogen, soil organic carbon, available phosphorus, exchangeable potassium, and soil particle sizes.

The soil pH in water (1:1 soil: water ratio) was determined using the pH meter; total nitrogen was determined using the procedure described by Bremner and Mulvaney (1982). The soil organic carbon was determined using the modified Walkley and Black's wet oxidation method as outlined by Nelson and Sommers (1982) whilst the available phosphorus was determined using the procedure described by Bray and Kurtz (1945). The exchangeable potassium was determined using the flame photometer. The soil particle sizes were determined using the hydrometer method described by Jones (2001).

Data analysis

Pearson correlation was performed among the soil chemical properties in order to establish relationship among them.

RESULTS

Initial soil properties

The soil in Makeni representing the savannah woodland was sandy clay loam in texture with a pH of 4.50. Organic carbon and total nitrogen were 67.60 t/ha and 8.06 t/ha respectively. Available phosphorus and exchangeable potassium were 6.60 mg/kg and 0.045 Cmol/kg respectively (Table 1). In Sumbuya representing the transitional rainforest, the soil was sandy loam in texture with a pH of 5.20; whilst organic and total nitrogen content was 114.40 t/ha and 10.67 t/ha respectively. The available phosphorus and exchangeable potassium were 24.50 mg/kg and 0.047 Cmol/kg respectively (Table 1). For Segbwema representing the rainforest, the soil was also sandy loam with a pH of 5.30. The organic carbon and total nitrogen content were 132.60 t/ha and 11.70 t/ha respectively. The available phosphorus and exchangeable potassium were 36.30 mg/kg and 0.054 Cmol/kg respectively (Table 1).

Table 1 The physicochemical composition of the soil in the three agro-ecological zones before establishing the trial.

Treatment	Agro-ecological zones		
	Savannah woodland (Makeni)	Transitional rainforest (Sumbuya)	Rainforest (Segbwema)
pH (Water)	4.50	5.20	5.30
Organic carbon (t/ha)	67.60	114.40	132.60
Total nitrogen (t/ha)	8.06	10.67	11.70
Available phosphorus (mg/kg)	6.60	24.5	36.30
Exchangeable potassium (Cmol/kg)	0.045	0.047	0.054
Electrical conductivity	115.00	266.00	66.00.00
Soil texture	Sandy clay loam	Sandy loam	Sandy loam
Sand (%)	71.40	77.36	65.40
Silt (%)	10.00	4.00	12.0
Clay (%)	18.60	18.64	22.6

Changes in soil nutrient status at harvest of the cassava at the three agro-ecological zones

Soil pH

The initial pH values for the agro-ecological zones in Makeni, Sumbuya, and Segbwema were 4.50, 5.20, and 5.30 respectively (Table 2). The pH at harvest of the cassava ranged from 4.30-6.60, 4.35-4.70, and 4.60-4.90 under all the cropping systems for the agro-ecological zones in Makeni, Sumbuya, and Segbwema respectively. At harvest of the cassava, the pH values were decreased under all the cropping systems in the three agro-ecological zones except for the cassava-soybean cropping system in the savannah woodland in Makeni, which recorded a slight increase in pH of 4.44% (Table 2). The highest percentage decrease in pH was recorded in the transitional rainforest zone in Sumbuya (12.77%) followed by the rainforest zone in Segbwema and the savannah woodland zone in Makeni (9.91%).

Concerning the cropping systems, the highest percentage decrease in pH was recorded for the sole cassava (11.37%) followed by cassava-cowpea (9.00%), cassava-groundnut (7.09%), and cassava-soybean system (4.24%). In general, the soil pH under all the cropping systems and agro-ecological zones was strongly acidic.

Table 2 Effect of cropping systems on soil pH in the three agro-ecological zones over two cropping seasons

Soil pH (1:1 H_20)													
	Agro-ecological zone												
	Savannah woodland (Makeni)				Transitional rainforest (Sumbuya)				Rainforest (Segbwema)				Mean (%)
	Initial	Final	Change	% Change	Initial	Final	Change	% Change	Initial	Final	Change	% Change	
Cropping system													
Sole Cassava	4.50	4.30	-0.20	-4.44	5.20	4.35	-0.85	-16.46	5.30	4.60	-0.70	-13.21	**-11.37**
Cassava-cowpea	4.50	4.40	-0.10	-2.22	5.20	4.50	-0.70	-13.46	5.30	4.70	-0.60	-11.32	**-9.00**
Cassava-groundnut	4.50	4.40	-0.10	-2.22	5.20	4.60	-0.60	-11.53	5.30	4.90	-0.40	-7.54	**-7.09**
Cassava-soybean	4.50	4.60	0.20	4.44	5.20	4.70	-0.50	-9.61	5.30	4.90	-0.40	-7.54	**-4.24**
Mean				**-1.48**				**-12.77**				**-9.91**	

Soil organic Carbon

Soil organic carbon increased at the harvest of the cassava across all the cropping systems in the savannah woodland zone in Makeni by 28.84% (Table 3). However, it was observed to decrease harvest of the cassava by 40.37% and 9.69% in the transitional rainforest zone in Sumbuya and the rainforest zone in Segbwema respectively. For the cropping systems, the percentage decrease in soil organic carbon at harvest of cassava was higher for the sole cassava (26.27%) followed by the cassava-cowpea (12.08%), and the cassava-groundnut system (0.92%) (Table 3). On the other hand, soil organic carbon was on average higher by 10.92% at harvest of the cassava for the cassava-soybean cropping system.

Table 3. Effect of cropping system on soil organic carbon in three agro-ecological zones over two cropping seasons

Soil organic carbon (t/ha)													
	Agro-ecological zone												
	Savannah woodland (Makeni)				Transitional rainforest (Sumbuya)				Rainforest (Segbwema)				Mean (%)
	Initial	Final	*Change	% Change	Initial	Final	*Change	% Change	Initial	Final	*Change	% Change	
Cropping system													
Sole Cassava	67.60	70.20	2.60	3.84	114.40	59.80	-54.60	-47.77	132.60	85.80	-46.20	-34.84	**-26.27**
Cassava-cowpea	67.60	88.40	20.80	30.76	114.40	62.40	-52.00	-45.45	132.60	104.00	-28.60	-21.56	**-12.08**
Cassava-groundnut	67.60	91.00	23.40	34.61	114.40	65.00	-49.40	-43.26	132.60	140.40	7.80	5.88	**-0.92**
Cassava-soybean	67.60	98.80	31.20	46.15	114.40	85.80	-28.60	-25.00	132.60	148.20	15.60	11.76	**10.97**
Mean				**28.84**				**-40.37**				**-9.69**	

Total soil Nitrogen

The total soil nitrogen content at harvest of the cassava was observed to increase in the three agro-ecological zones and the cropping systems except for the sole cassava system (Table 4). The percentage increase in the total soil nitrogen content was higher in the rainforest zone in Segbwema (1.73%) followed by the transitional rainforest zone in Sumbuya (1.24%) and the savannah woodland zone in Makeni (1.11%) (Table 4). In the case of the cropping system, the highest increase in the total nitrogen was recorded for the cassava-soybean system (10.84%) followed by the cassava-groundnut system (6.27%), cassava-cowpea system (2.62%), and the sole cassava (14.31%) across the three agro-ecological zones (Table 4).

Table 4. Effect of cropping system on the total soil nitrogen in three agro-ecological zones over two cropping seasons.

Soil total nitrogen (t/ha)													
									Agro-ecological zone				
	Savannah woodland (Makeni)				Transitional rainforest (Sumbuya)				Rainforest (Segbwema)		Mean (%)		
	Initial	Final	*Change	% Change	Initial	Final	*Change	% Change	Initial	Final	*Change	% Change	
Cropping system													
Sole Cassava	8.06	6.10	-1.96	-24.32	10.66	9.36	-1.30	-12.19	11.70	10.95	-0.75	-6.41	**- 14.31**
Cassava-cowpea	8.06	8.32	0.26	3.22	10.66	10.92	0.26	2.43	11.70	11.96	0.26	2.22	**2.62**
Cassava-groundnut	8.06	8.84	0.76	9.42	10.66	11.18	0.53	4.97	11.70	12.22	0.52	4.44	**6.27**
Cassava-soybean	8.06	9.36	1.30	16.12	10.66	11.70	1.04	9.75	11.70	12.48	0.78	6.66	**10.84**
Mean				**1.11**				**1.24**				**1.73**	

Soil available Phosphorus

There was a general reduction in soil available phosphorus concerning the cropping systems in the three agro-ecological zones (Table 5). The percentage reduction across the cropping systems ranged from 16.67-71.71%, 44.90-70.61%, and 47.77-76.86% for the agro-ecological zones in Makeni, Sumbuya, and Segbwema respectively. For the agro-ecological zones, Sumbuya in the transitional rainforest (58.67%) recorded the highest reduction followed by Segbwema in the rain forest (52.75%), and Makeni in the savannah woodland (47.37%). Pertaining to the cropping systems, the highest reduction in available phosphorus was recorded for the cassava-soybean system (72.89%) followed by the cassava-groundnut system (56.54%), cassava-cowpea (54.39%), and the sole cassava (36.23%) (Table 5).

Table 5 Effect of cropping system on the soil available phosphorus in three agro-ecological zonesover two cropping seasons

Available phosphorus (mg/kg)													
	Agro-ecological zone												
	Savannah woodland (Makeni)				Transitional rainforest (Sumbuya)				Rainforest (Segbwema)				Mean (%)
	Initial	Final	*Change	% Change	Initial	Final	*Change	% Change	Initial	Final	*Change	% Change	
Cropping system													
Sole Cassava	6.60	5.50	-1.10	-16.67	24.50	13.50	-11.00	-44.90	36.30	19.20	-17.10	-47.11	**-36.23**
Cassava-cowpea	6.60	3.90	-2.70	-40.90	24.50	7.30	-17.20	-70.20	36.30	17.40	-18.90	-52.07	**-54.39**
Cassava-groundnut	6.60	2.60	-4.00	-60.60	24.50	12.50	-12.00	-48.98	36.30	14.50	-21.80	-60.05	**-56.54**
Cassava-soybean	6.60	1.90	-4.70	-71.21	24.50	7.20	-17.30	-70.61	36.30	8.40	-27.90	-76.86	**-72.89**
Mean				**-47.35**				**-58.67**				**-59.02**	

Soil exchangeable Potassium

Similarly, there was a general decrease in exchangeable potassium across the cropping systems and agro-ecological zones (Table 6). The percentage reduction was higher in the rainforest zone in Segbwema (38.42%) followed by the transitional rainforest zone in Sumbuya (37.77%) and the savannah woodland zone in Makeni (33.33%). The percentage reduction in exchangeable potassium ranged from 22.22-48.88%, 27.66-51.06%, and 25.00-50.00% for the agro-ecological zones in Makeni, Sumbuya, and Segbwema respectively. In the case of the cropping systems, the highest mean percentage reduction was recorded for the cassava-soybean system (49.98%) followed by the cassava-groundnut system (39.64%), the cassava-cowpea system (31.13%), and the sole cassava (25.26%) (Table 6).

Table 6 Effect of cropping system on the soil exchangeable potassium in three agro-ecological zones over two cropping seasons

Exchangeable potassium (Cmol/kg)													
	Agro-ecological zone												
	Savannah woodland (Makeni)				Transitional rainforest (Sumbuya)				Rainforest (Segbwema)				Mean (%)
	Initial	Final	*Change	% Change	Initial	Final	*Change	% Change	Initial	Final	*Change	% Change	
Cropping system													
Sole Cassava	0.045	0.035	-0.010	-22.22	0.047	0.034	-0.013	-27.66	0.054	0.040	-0.014	-25.92	**-25.26**
Cassava-cowpea	0.045	0.034	-0.011	-24.44	0.047	0.032	-0.015	-31.91	0.054	0.034	-0.020	-37.03	**-31.13**
Cassava-groundnut	0.045	0.028	-0.017	-37.77	0.047	0.028	-0.019	-40.42	0.054	0.032	-0.022	-40.74	**-39.64**
Cassava-soybean	0.045	0.023	-0.022	-48.88	0.047	0.023	-0.024	-51.06	0.054	0.027	-0.027	-50.00	**-49.98**
Mean				**-33.33**				**-37.77**				**-38.42**	

Correlation among soil chemical properties across the agro-ecologicalzones

From the results, a strong, positive, and significant correlation was recorded between pH with soil organic carbon in the savannah woodland zone in Makeni (P = 0.0017, r = 0.8023), the transitional rainforest zone in Sumbuya (P = 0.0019, r = 0.8621), and the rainforest zone in Segbwema (P = 0.0002, r = 0.8821) (Table 7). For soil total nitrogen, a strong, positive, and significant correlation was also recorded between pH with soil total nitrogen for the agro-ecological zones in Makeni (P = 0.0014, r = 0.8246), Sumbuya (P = 0.0016, r = 0.8446), and Segbwema (P = 0.0002, r = 0.8712) (Table 7).

In the case of the correlation between soil organic carbon with total nitrogen, a very strong, positive, and significant correlation was recorded for both agro-ecological zones in Segbwema (P = 0.0069, r = 0.9930) and Sumbuya (P = 0.0443, r = 0.9257) whilst, a moderately strong, positive, and significant correlation was recorded in the savannah woodland zone in Makeni (P = 0.0045, r = 0.7245) (Table 7).

Table 7 Correlation matrix among soil chemical properties in three agro-ecological zones

Pearson Correlation Coefficients Prob> |r| under H0: Rho=0															
	Agro-ecological zone														
Soil chemical properties	Savannah woodland					Transitional rainforest					Rainforest				
	pH	SOC	TN	AP	EP	pH	SOC	TN	AP	EP	pH	SOC	TN	AP	EP
pH	1.00	0.80 0.001	0.82 0.001	-0.86 0.13	-0.72 0.2765	1.00	0.88 0.0002	0.87 0.0002	-0.32 0.67	0.23 0.76	1.00	0.86 0.002	0.84 0.002	0.21 0.78	-0.04 0.95
SOC	0.80 0.002	1.00	0.72 0.005	-0.96 0.03	-0.59 0.40	0.88 0.0002	1.00	0.99 0.007	-0.90 0.09	-0.89 0.101	0.86 0.002	1.00	0.92 0.04	-0.85 0.14	-0.93 0.27

TN	0.82 0.00 2	0.72 0.00 5	1.00	-0.96 0.03	-0.57 0.42	0.87 0.00 02	0.99 0.00 7	1.00	- 0.8 0 0.1 9	-0.98 0.01	0.84 0.00 2	0.92 0.04	1.00	- 0.7 2 0.2 7	-0.85 0.14
AP	-0.86 0.13	-0.96 0.03	-0.96 0.03	1.00	0.76 0.23	-0.32 0.67	- 0.90 0.09	-0.80 0.19	1.0 0	0.84 0.15	0.21 0.78	-0.85 0.14	-0.72 0.27	1.0 0	0.72 0.27
EP	-0.72 0.27	-0.59 0.40	-0.57 0.42	0.76 0.23	1.00	0.23 0.76	- 0.89 0.10	-0.98 0.01 3	0.8 4 0.1 5	1.00	-0.04 0.95	-0.93 0.06	-0.85 0.14	0.7 2 0.2 7	1.00

DISCUSSION

Soil nutrients are essential for plant growth and development. The results from the study show that cassava-legume intercropping systems can affect the soil in terms of pH, organic carbon, total nitrogen, available phosphorus, and exchangeable potassium.

The soil pH at harvest in the three agro-ecological zones and cropping systems was very strongly acidic. There was a decrease in pH of the soil concerning cropping systems and agro-ecological zones, which could be attributed probably to the removal of large quantity of nutrients from the soil especially, bases by the component crops. This result concord with the findings of Minhas et al. (1995) who reported a reduction in the mean pH from 6.7-5.7 when cassava was intercropped with soybean. The reduction in pH was higher for the agro-ecological zones in Sumbuya and Segbwema compared to Makeni probably because higher yields of the component crops were recorded in both zones compared to Makeni. Furthermore, the sole cassava recorded a higher reduction in pH compared to the intercropping systems probably because this system extracted more soil nutrients in the form of bases from the soil than it added to it. On the contrary, the slight increase in pH recorded in the savannah woodland in Makeni for the cassava-soybean cropping system suggests that intercropping could improve soil pH. The reason for the observed increase according to Cong and Merckx (2005) could be probably due to the transformation of nitrogen and the release of metal ions resulting from the decomposition of organic residues. Furthermore, Matusso et al. (2012) and Owusu and Sadick (2016) argued that, the increase in soil pH value in intercropping systems shows that intercropping could decrease soil acidity as a result of higher organic matter production.

This observation concord with the findings of Esekhade and Idoko (2010) who reported higher soil pH in the legume-cereal intercropping system compared to their counterpart under the mono-cropping system. In addition, Schoenerberger et al. (2002) reported changes in soil pH from strongly acidic to slightly acidic in the maize-legume intercropping system.

The result further reveals a strong, positive, and significant correlation between pH with soil organic carbon, and between pH with total nitrogen; indicating that the higher the pH the greater the availability of these nutrients to the plant. This further shows that the availability of these two soil nutrients were strongly affected by soil pH; as it determines the variation of soil microorganism community structure and diversity (Tripathi et al., 2018), which controls the process of decomposition and mineralization of soil organic matter and the subsequent released of nutrients to plants. Furthermore, Rousk et al. (2010) showed that the relative abundance and diversity of bacteria were positively related to pH. This effect impacts the mineralization process leading to higher nitrogen content in soils with higher pH. This result concord with the findings of Xu et al. (2019) who reported positive correlations between soil organic carbon and pH in central-eastern Europe. On the contrary, Reisser et al. (2016) reported a general negative correlation between organic carbon and nitrogen with pH under natural conditions at various sites. This suggests that a relatively low pH favours the accumulation of organic matter (Zhou et al., 2019). This negative correlation shows that high pH values tend to have lower soil organic carbon content and total nitrogen whilst low pH tends to have higher soil organic carbon and total nitrogen content. The reason adduced by these authors for the negative correlation is that soil organic matter upon decomposition releases organic acids which lead to low pH value. Soil pH is a major driver controlling nutrient availability for plants and thus, influences biomass production indirectly (Bolan et al., 2003; Wang et al., 2012).

Soil organic carbon is one of the key attributes in assessing soil health; it is generally positively correlated with crop yield (Bennett et al., 2010). Murphy (2015) opined that, important functional processes in soil such as the ability to store nutrients especially, nitrogen, water holding capacity, and aggregate stability are strongly influenced by the organic carbon content in the soil. It is also important for increased agricultural production because organic matter helps improve soil structure and cation exchange capacity and hold water; thus, it has a positive impact on soil fertility (West and Post, 2002).

From the result, soil organic matter was observed to increase across cropping systems in the savannah woodland in Makeni probably due to the decomposition of a lot of biomass returned from cassava and component crops during the growing season as reported by Ojeniyi and Adetoro (1993) who noted an appreciable increase in soil organic carbon following the decomposition of leaves of Gliricidia sepium. The authors adduced the increase in soil organic carbon after cropping to the high rate of mineralization informed by the fast rate of decomposition of legume leaves due to their low C: N ratio. Moreover, the increase in soil organic carbon at harvest could also be because the cultivation of cassava may have minimized erosion and microbial decomposition rate considerably while maintaining favorable soil moisture conditions. According to King et al. (2019), regardless of the decomposition rates, where organic inputs outweigh organic matter losses, soil organic carbon should increase even though slowly.

This result conforms to the findings of Matusso et al. (2012) who reported higher soil organic matter with intercropping. In addition, Ispandi (2002) reported an increase in organic carbon of 12% and 56% when cassava was intercropped with maize and groundnut respectively. Similarly, Nath et al. (2003), Aulakh et al. (2004), and Swain (2016) have also reported an increase in the organic carbon content of orchard soil due to intercropping practices in fruit orchards.

On the contrary, there was a depletion of soil organic carbon for the agro-ecological zones in Sumbuya and Segbwema probably because of higher nutrient uptake by component crops than the quantity of nutrients supplied through the legumes (Jones, 2016). Another possible reason could be due to higher yields of component crops reported for these agro-ecological zones. This result concord with the findings of Yan et al. (2006) who reported the possibility of rapid nutrient depletion under intercropping systems due to the combined demands of the individual intercrops for nutrients.

Furthermore, soil organic carbon was observed to decrease among the cropping systems except for the cassava-soybean system which recorded an increase in soil organic carbon. The rate of soil organic carbon depletion was higher for the sole cassava probably because cassava being a wide-spaced crop, most of the soil was left vacant under the sole cropping system resulting in a higher loss of soil organic matter by oxidation and less addition of soil biomass. The higher soil organic carbon recorded concerning the cassava-soybean system could be because a higher quantity of nutrients was supplied to the system through the legumes than the amount of nutrient that was taken up by the component crops. This result agrees with the findings of Akinnifesi et al. (2007) and Sebetha (2015) who reported an increase in soil organic carbon under the cereal-legume intercropping system.

The result further reveals a strong, positive, and significant correlation between soil organic carbon and total nitrogen across the three agro-ecological zones. This shows that an increase in soil organic carbon will be followed by an increase in total nitrogen as reported by Brevik et al. (2018). This result concord with the findings of Sadovnikova et al. (1996) who reported a strong, positive correlation between soil organic carbon with total nitrogen.

Pertaining to the total nitrogen, there was a general increase in the total nitrogen content across cropping systems in the three agro-ecological zones except for the sole cassava, which recorded a decrease in total nitrogen content at harvest of the cassava. The increase in total nitrogen content across the agro-ecological zones was generally slight, probably due to the excessive removal of nitrogen by cassava for root formation in all the zones. The general decrease in the total nitrogen for the sole cassava system could be because cassava removes a large amount of nitrogen from the soil for root yield formation as reported by Obigbesan (1977) and CIAT (1982). Furthermore, it has been reported by Padwick (1983) that African soils show nutrient-deficiency problems after a short period of cultivation, with nitrogen being the most rapidly depleted nutrient. Other possible reasons for the observed depletion of nitrogen under the sole cassava system could be because cassava is normally planted in a wide spacing at the start of the rainy season when the soil is exposed and has not been covered by a canopy and thus, susceptible to erosion.

On the other hand, the observed increase in total nitrogen content across the intercropping systems could be because legumes have the ability to trap and fix nitrogen into the soil through their root nodules as reported by Crews and Peoples (2004). Furthermore, the large amount of biomass produced by both the cassava and the legumes after mineralization could have released a large amount of nitrogen into the soil. This result corroborates the findings of Nweke (2016) who reported significant levels of nitrogen in plots containing maize that was intercropped with groundnut. Similar results of an increase in the available nitrogen content of the soil through intercropping in mango orchards have been reported by Swain (2016).

Furthermore, Nnadi and Haque (2017) have shown that legumes might contribute about 30% N from the nitrogen fixation process to other crops in intercropping and crop rotation. Bundy and Andraski (2005) also reported that the residues of corn returned to the field can contribute 50-100 kg N/ha where 5-20% of nitrogen residue can still be used by the next crop (Bundy and Andraski, 2005).

Concerning available phosphorus, there was a general reduction across cropping systems in the three agro ecological zones. The reason for the general decline in available phosphorus could be related probably to the fact that the component crops may have taken up a large amount of phosphorus from the soil. The above observation agrees with the findings by Onwueme and Sinha (1991). These authors reported that root crops take up more Phosphorus and Potassium from the soil than any other crop species. The reduction in available phosphorus was higher for the agro-ecological zones in Segbwema and Sumbuya probably due to the higher yields of component crops reported in the two agro-ecological zones. Furthermore, the reported decrease in available phosphorus of the intercrops compared to the sole cassava could be attributed to the excessive demand and use of phosphorus by legumes for nitrogen fixation and other physiological processes. The result conforms to the findings of Nweke and Emeh (2013) who reported that legumes required an abundant amount of phosphorus in the soil for nitrogen fixation and growth. This result is in contrast to the findings of Carel (2006) who reported an increase in soil-available phosphorus under intercropping involving legumes and adduced this to the mineralization of organic phosphorus, which in turn, results in the release of more phosphorus for crop use.

Similarly, a general reduction in exchangeable potassium was recorded across cropping systems in the three agro-ecological zones probably because there is always a high demand for nutrients by component crops in intercropping systems (Yahaya et al., 2014). Similar observation was also reported by Kurt (1984). The depletion of exchangeable potassium was more severe in the rainforest zones in Segbwema and the transitional rainforest zone in Sumbuya compared to the savannah woodland zone in Makeni probably due to the higher tuberous root yield that was produced at these two zones as potassium is the most limiting factor in cassava nutrition. The indispensability of potassium in cassava nutrition had been demonstrated by many studies (Nyi, 2014; Pypers et al., 2011). This result agrees with the findings of Bharabwaj et al. (1994) who reported that the uptake of potassium by crops generally increases with an increase in crop yield.

Furthermore, the higher rate of potassium depletion recorded with respect to the intercropping system compared to the sole cassava could be probably due to the removal of potassium from the soil by both the cassava and component crops. Another factor that can be implicated in the decrease in exchangeable potassium is the inability of the legumes to fix appreciable quantities of potassium into the soil, unlike nitrogen, as legumes are generally known for nitrogen fixation. This result concord with the finding of Yahaya et al. (2014) who reported rapid nutrient depletion under intercropping systems due to the combined demands of the individual intercrops for nutrients. The decrease among intercropping systems was higher for the cassava-soybean system probably because of the higher root yield recorded for this cropping system in the three agro-climatic zones.

CONCLUSIONS

The result of this study has established that intercropping cowpea, soybean, and groundnut with cassava decreased soil pH among cropping systems in the three agro-ecological zones except for the cassava-soybean system in the savannah woodland zone in Makeni. Soil organic carbon increased in the savannah woodland zone in Makeni but decreased in the rainforest zone in Segbwema and the transitional rainforest zone in Sumbuya among the cropping systems except for the cassava-soybean system. Soil total nitrogen increased across cropping systems in the three zones except for the sole cassava. Exchangeable potassium and available phosphorus decreased under all cropping systems at all three zones. Furthermore, a strong, positive correlation was observed between organic carbon and total nitrogen with pH on the one hand, and between organic carbon and total nitrogen on the other.

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Authors' Contributions

All authors contributed equally to the conception and design of the study.

Competing Interests

The authors have declared that no competing interests exist.

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