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Influence of Cover Crop Mixtures on Soil Physical and Chemical Properties in Maize Production

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ABSTRACT

Land use intensification, soil degradation and weed infestation limit the productivity of nutrient-sensitive crop such as maize. Mixed cover cropping has potentials to address these challenges in an ecological friendly manner. Field experiments were conducted between 2007 and 2009 at the Taraba State College of Agriculture Teaching Farm, Jalingo, Nigeria to evaluate the effects of a leguminous cover crop, Akidi (A), *Vigna unquiculata sub-sp sequipedalis)* and two non-leguminous cover crops (Melon M) and Sweet potato (S) planted in all possible combinations at three planting densities used primarily for weed control on soil conservation and maize production. Treatments include 20,000($_1$), 30,000($_2$) and 40,000($_3$) stands ha^{-1} of AM (AM_1, AM_2, AM_3), AS (AS_1, AS_2, AS_3), MS (MS_1, MS_2, MS_3) and AMS (AMS_1, AMS_2, AMS_3), weeded (3+6 Weeks After Planting, WAP) (C_1) and unweeded (C_2) checks replicated three times in a randomized complete block design. Descriptive statistics and Analysis of Variance were used to analyze data and the treatment means were compared using standard error at 5 %. A general decrease in calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), pH, exchangeable acidity, available phosphorus (AV-P), % silt and cation exchange capacity (CEC) but a slight increase in organic carbon, total nitrogen (TN), % clay and % fine sand. The AMS treated plots had the highest magnitude of increase in organic carbon (OC). The order of OC improvement was AMS > AM >MS >AS. While increase in TN was AMS > AM >AS >MS. Reduction in AV-P was highest in AM treated plots (90.4%), followed by AS and then MS, while AMS caused the least reduction in AV-P. Fine sand was slightly increased in most treatments. Use of cover crop mixtures for weed management in maize decreased all exchangeable cations, pH, AV-P and CEC, and improved OC, TN and clay content.

Introduction

Sustainable maize production at small holder level, especially in the Savannah agroecological zone are faced with the challenge of unpredictable rainfall pattern and low soil fertility (Buah *et al*., 2017). The challenge of increasing human population in tropical Africa resulted in land-use intensification and increasingly reduced fallow period which grossly limits the productivity of the soil due to loss of nutrients and soil degradation. Planted fallow becomes an alternative that should be desired, especially for nutrient-sensitive crops like maize. Conventional agriculture could decline productive capacity of a given agroecosystem as a result of adverse change in soil's physical, chemical and biological attributes (Schlindwein *et al*., 2012). These results in unsatisfactory crop yield because of declining soil fertility, rapid soil mineralization due to high temperature and rainfall (Garcia *et al*., 2017). It was therefore necessary to ameliorate soil for sustainable soil quality and maize production. Sustainable crop production which aims at enhancing soil structures, water and nutrient-holding capacity is feasible with the use of cover crop mixtures that favour the farm families' objectives (Lu *et al*., 2000; Lampkin *et al*., 2015). Conservation agriculture which involves minimum tillage and usage of soil cover has resulted in sustainable land productivity (Fageria *et al*., 2005; Hallama *et al*., 2019) in the Americas (Bwalya and Friedrich, 2002) but has not been adequately exploited in most African countries (Lal, 1986); yet most soils in Nigeria especially in the Savannahs are highly weathered, with low inherent fertility and reduced soil organic matter, which is important in maintaining good soil physical properties and crop nutrients supply (Ssali and Vlek, 2002). Maintaining soil cover using legume cover crops (improved fallows) has been reported to preserve and foster organic matter balance in the soil (Dick, 1982; Calegari, 1998).

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Cover crop has been reported to influence soil's physical, chemical and biological properties when planted alone with the major crop or as a mixture (Weerasekara *et al*., 2017). The positive impact of cover crop in reducing erosion, rainfall erosivity, weed suppression and organic matter enhancement has been reported by several authors (Baets *et al*. 2011; Nascente and Stone, 2018). Michael *et al*. (2015) in their evaluation of sole planted akidi, melon or sweet potato in association with maize on soil physico-chemical properties observed that there was a decline in exchangeable cations, P, pH, exchangeable acidity, effective cation exchange capacity (ECEC) and the silt proportion; but organic carbon, N, fine sand increased in all the treatments over the years. The choice of akidi, a leguminous cover crop, melon and sweet potato in this study is for ease of adoption by farmers due to their high food values. Farmers choose to grow and manage specific cover crop types based on their own needs and goals, influenced by the biological, environmental, social, cultural, and economic factors of the food system within which farmers operate (Snapp *et al*., 2005). These cover crops are been grown with maize individually, without focus on the soil enhancement impact (Muhamman and Gungula, 2006). Mixtures of cover crops with increased diversity of the crop growing system is known to be more resilient to changing climate and has the potential to improve the dietary matrix of the rural populace.

Sharma *et al*. (2018a) observed that organic matter under cover crops was higher than bare soil treatment, and that cover crops significantly reduced P and nitrate-nitrogen (NO_3-N) quantity in the soil when they were alive and actively growing but provided same to next maize crop. They concluded that soil organic matter, nitrate-nitrogen, P, C and N can be conserved and or enhanced by cover crop. Maintenance of soil health and sustainability of agroecosystem can be realized using cover crops. Krstić *et al*. (2018) reported that soil water storage can be reduced by cover crop treatments especially during dry year and this ultimately reduce yield of the accompanying crop. The ECEC and available P could be reduced significantly ($p < 0.05$) in leguminous cover crop plots when compared with non-leguminous plot (Michael *et al*., 2015). Organic carbon was significantly ($p<0.05$) increased in potato (7.7 %), akidi (6.9 %) and melon plots (1.2 %), but reduced by 22.4 % in the unweeded plot. Similarly, nitrogen significantly ($p<0.05$) increased in the akidi (6.5 %), potato (7.7 %) plots, but declined by 36.0 % in melon plot. dos Passos *et al*. (2017) in their evaluation of fourteen cover crops on soil quality in Brazil, reported that the use of cover crop has the potential to improve the chemical quality of soil. Leguminous cover crops promote greater nitrogen cycling in an agroecosystem thereby boosting the availability to crop and minimize the use of nitrogenous fertilizers (Mahama *et al*., 2016). Cover crop help to reduce greenhouse gases effect (Lal, 2015) minimize soil erosion and compaction which are major causes of soil depletion and reduced crop yield. Decomposition of roots helps to increase soil pores in addition to restoration and maintenance of soil quality where crop residue is involved (Pereira *et al*., 2016; dos Passos *et al*., 2017). The amount of biomass produced, and the types of cover crops determine the effect on soil fertility. Cover crop mixtures shows better soil enhancement because of higher diversity than sole or less diverse systems. These gave rise to the concept of soil health mix, a combination of five species recommended by USDA (Chu, 2017). Degu *et al*. (2019) reported that rotation with legume recorded highest pH, CEC and total nitrogen, and that clay content in conserved system is greater than unconserved system because of continuous deposits of sediments. Mulugeta and Stahr (2010) on the other hand, reported low pH and P fixation, available P is high in legume due to large organic acids released from the roots which help to mobilize P. High organic matter in a system has been attributed to high rainfall and slow decomposition (Cattanio *et al*., 2008; Gmach *et al*., 2020).

Small-scale farmers would prefer cover crops that have some food or cash value in addition to weed control and soil improvement attributes. The rationale for using cover crop mixture includes the possibility of regulating rate and duration of decomposition and subsequent nutrient supply (Abdin *et al*., 2000). Little is known about the effects of mixed cover crops planted at various densities on soil properties in maize in the study area. Hence, this study was carried out to determine the effects of a leguminous cover crop, akidi, *Vigna unquiculata sub-sp sequipedalis)* and two non-leguminous cover crops (melon and sweet potato) planted in all possible mixtures at three (3) planting densities used primarily for weed management on the physical and chemical properties of soil and maize production.

Materials and Methods

Experimental site

Field trials were conducted at the Teaching farm of Taraba State College of Agriculture (08^0 50' N, 11^0 50' E) in the Northern Guinea Savannah ecological zone. Jalingo has a wet and dry tropical climate with rainy season of about 150 days and an average annual rainfall of about 700 mm – 1000 mm. Mean annual temperature of Jalingo is about 28^{o}C with maximum temperatures ranges between 30^{0}C and 39.4^{0}C. The minimum temperatures range between 15^{o}C to 23^{o}C. The rainy season is between May and October while the dry season is from November to April.

Land preparation

The land used for the experiment was cleared manually using cutlass to reduce the few shrubs scattered on the field. Ploughing was done once using tractor.

Experimental design and layout

The experiment was designed to study the influence of three planting densities of mixtures of akidi/melon (AM), akidi/sweet potato (AS), melon/sweet potato (MS) or akidi/melon/sweet potato (AMS) on some soil properties and performance of maize. The experimental design was a randomized complete block with three replications. There were 14 mixed cover treatments as in Table 1. Each plot measured 4m x 4m with 1m space between plots and 2m border separating blocks. The total land area was (69m x 16m) 1104m^2.

Table 1. Cover crop mixtures weed management treatments

#	Treat	Plant population ha^{-1}
1	AM_1	Akidi + Melon at 10,000 each (20,000)
2	AM_2	Akidi + Melon at 15,000 each (30,000)
3	AM_3	Akidi + Melon at 20,000 each (40,000)
4	AS_1	Akidi + Sweet potato at 10,000 each (20,000)
5	AS_2	Akidi + Sweet potato at 15,000 each (30,000)
6	AS_3	Akidi + Sweet potato at 20,000 each (40,000)
7	MS_1	Melon + Sweet potato at 10,000 each (20,000)
8	MS_2	Melon + Sweet potato at 15,000 each (30,000)
9	MS_3	Melon + Sweet potato at 20,000 each (40,000)
10	AMS_1	Akidi + Melon + Sweet potato at 6,666 each (20,000)
11	AMS_2	Akidi + Melon + Sweet potato at 10,000 each (30,000)
12	AMS_3	Akidi +Melon + Sweet potato at 13,333 each (40,000)
13	C_1	Hand weeded control (3+6 WAP)
14	C_2	Unweeded control

Planting and trial management

Planting of maize was done on 16th June, 2007; 30th June, 2008 and 13th June, 2009. Cover crops were planted within 24hrs. Maize was sown three seeds per hole at 25cm x 100cm spacing, to give a population of 40,000 plants ha^{-1} in all the plots and the seedlings were latter thinned to one plant per stand. The plot size was 4m x 4m. There were 64 stands of maize per plot (i.e 4 rows of 16 stands/ row). Akidi and melon seeds were sown 4/hole, while 2-3 sweet potato vines/hole, spaced 50 cm x 100 cm and latter thinned to give the required population densities of 20,000 (One stand/hill); 30,000 (One and two stands in alternate hills) or 40,000 (two stands/hill) plants ha^{-1}. All mixed cover crop treated plots were weeded once at 3 weeks after planting to enhance establishment and spread. In each of the cover crop mixtures, cover crops were planted at 1:1 ratio in two-way mixtures and 1:1:1 in three-way mixtures. The cover crops were planted in alternate rows/hills. Field management was similar for all the treatments till harvesting.

Soil sampling and analysis

Prior to planting, 40 surface soil samples were collected from different plots with soil auger at 0-15 cm depth. These were bulked together, air-dried at room temperature, crushed in a mortar to break the soil aggregates and sieved with a 2mm sieve to remove large particles, debris and pebbles as described by Food and Agriculture Organisation (2006). Routine analysis was carried out to determine some physical and chemical properties of the soils. Soil pH was measured with the glass electrode pH meter in a 1:1 soil to water ratio and 1:2 soil to $CaCl_2$ ratio (Udo *et al.*, 2009). The organic carbon was determined by the Walkley and Black wet oxidation method (Nelson and Somers, 1982).

Total N was determined by the micro Kjeldahl digestion method by heating the samples at 360-410^{0}C with concentrated sulphuric acid (H_2SO_4), distilled with NaOH as described by Bremner (1996), while AV-P was extracted by Bray's 1 method (Bray and Kurtz, 1945) and read from the spectrophotometer. Exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) were determined by repeated extraction procedure with neutral 1M NH_4OAc (pH7) solution. The $Ca^{2+}$and Mg^{2+} in solution were read on an atomic absorption spectrophotometer while K^+, Na^+ were read on the flame photometer (IITA, 1979). Soil particle-size distribution was determined by the hydrometer method using sodium hexametaphosphate (Calgon) as the dispersant; as described by Gee and Or (2002). Exchangeable acidity (H^+) of the soil was determined by titration method. Effective cation exchange capacity (ECEC) was calculated as the sum of the exchangeable bases (K^+, Na^+, Ca^{2+} and Mg^{2+}) (Chapman, 1965).

Data collection (Maize)

These were collected from 10 tagged maize plants selected from the two middle rows, exempting the boarder plants, in each plot. The dry cob and grain yield per hectare, as well as 100 seeds weight was used to assess the yield performance.

Data analysis

Descriptive statistics and Analysis of Variance using the generalized model of SAS (1995) were used to analyse data. Treatment means were compared using standard error at 5 % probability level (Clewer and Scarisbrick, 2001, Gomez and Gomez, 1984).

Results and Discussion

Initial soil properties

The pre-cropping physico-chemical characteristics of the soil of the experimental site are shown in Table 2. The status of the soil before planting shows that the soil is sandy loam, slightly acidic with nutrient elements and organic carbon less than critical levels according to Enwenzor *et al.* (1989). Total N (0.1%) and available phosphorus (4.8 mg kg^{-1}) are low. The exchangeable cations ranged from 0.18 cmol^{-1} for K to 2.36 cmol^{-1} for Ca.

Table 2. Pre-cropping soil physico-chemical properties of the experimental site

Soil Properties	Values
pH 1.1(H_2O)	6.72
pH 1.2($Cacl_2$)	6.45
Organic carbon (%)	0.741
Total N (%)	0.098
Avail. P ($mgkg^{-1}$)	4.75
Exchangeable cations (cmol kg^{-1})	
Ca	2.36
Mg	0.57
Na	0.21
K	0.18
Particle size (%)	
Sand	73.3
Silt	14.0
Clay	12.7

Change in soil chemical properties

The effect of cover crop mixtures on Exchangeable cations (Calcium, Magnesium, Potassium Sodium) and Exchangeable Acidity is shown in Tables 3 and 4.

Calcium (Ca^{2+})

The effect of cover crop mixture (CCM) on Ca^{2+} is presented in Table 3. In 2008, cover crops mixture significantly influenced Ca^{2+} of the soils. The highest Ca^{2+} was recorded in AM (2.71) followed by AS, C_2, AMS, MS and C_1 recorded the lowest Ca^{2+}. This could be as a result of higher rate of decomposition and mineralization in AM plots due to the presence of melon thereby increasing Ca^{2+} level in the soils, this was in line with Arévalo-Gardini *et al.* (2015), who reported higher soil nutrients status as a result of high mineralization rates. Irrespective of cover crop, there was a decrease in Ca^{2+} status with increasing plant densities. These values were higher than in C_1 and C_2 except at the maximum population. The higher biomass produced at higher densities required higher nutrients including Ca^{2+} thus reducing the Ca^{2+} level. This was in contrast with Beck *et al.* (2016) who reported increase in Ca^{2+} over two years. The absorption of any given nutrient from the soils by the crops will inevitably reduce the amount of such nutrient in the soils, this corroborated the findings of Chen *et al.* (2019). In 2009, the highest Ca^{2+} level was recorded in C_1 (4.07) with the lowest in AMS plots (1.88). The order C_1>C_2>AM>AS/MS/AMS. The low demand of Ca^{2+} in plots without cover crops could be responsible for the higher Ca^{2+} level recorded, in addition to possible release in a well pulverised soil of C_1, which was weeded twice. The effect of planting densities of CCM followed the 2008 trend (Table 4). Within each cover crop group, the plant population influence was not consistent. There was a general decrease in Ca^{2+} between 2008 and 2009 in all the CCM plots but an increase in control plots. The reduction in Ca^{2+} between 2008 and 2009 reflected the continuous usage of the plots which means the nutrients over the years were used up the by plants. The observed higher level of reduction in AM could be as a result of leaching from the almost bare surface left due to fast decomposition of melon component when compared to other treatments; this was in agreement with Michael *et al.* (2015) who reported decrease in Ca^{2+} level in sole planted akidi, melon or sweet potato with maize. All the CCM used calcium more than the untreated plots. The increase was highest in C_1 when compared to C_2. The highest increase observed in C_1 could be associated to enhanced release of Ca^{2+} because of frequent soil pulverisation, having been weeded twice. Calcium was significantly reduced by 24.4% in AM plot when compared with AMS (19.3%) and MS (14.16%) respectively.

Magnesium (Mg^{2+})

The trend of magnesium (Mg^{2+}) in the soils was similar to that of Ca^{2+}. In 2008, the highest Mg was recorded in C_2 (0.43) which was significantly higher than the rest except AM plots (0.42). The least was observed in C_1. Among the cover crop mixtures, the order was AM>AS/MS>AMS. The significantly low Mg in AMS plots reflected the higher diversity with increasing demand for magnesium by the three mixed cover crops when compared with others. These gave rise to better soil health mix, similar to a combination of five species recommended by USDA (Chu, 2017). Across the cover crops, Mg^{2+} level in 20,000 and 30,000 stands ha^{-1} plots were similar but higher than the 40,000 stand per ha. This still showed slight decrease in Mg^{2+} level with increase in plant densities. Within each cover crop groups, the trends were inconsistent except in AMS where significant reduction in Mg^{2+} was associated with increased density. The highest Mg^{2+} was recorded in AM_1 (0.49) and the least in AS_3 and AMS_3 (0.28), respectively. In 2009, the control plots recorded significantly higher Mg^{2+} level when compared with CCM plots. Among the CCM treated plots, the order MS>AM/AMS>AS was observed. There was generally a slight decrease between 2008 and 2009 in all the CCM plots except MS and control plots. Density significantly influences Mg^{2+} in 2009 with the maximum recorded at 30,000 followed by 20,000 and 40,000 stands ha^{-1} respectively. The percentage reduction in Mg^{2+} in AS plots (18%) was significantly higher than in AMS plots (2.78%). The demand for Mg^{2+} by akidi in AM and AS plots over the years might be responsible for the higher Mg^{2+} reduction when compared with AMS, having low component of akidi or MS without akidi. Akidi as a leguminous vegetable cowpea with strong root network and aggressive growth is likely to exploit more nutrients from the soils, this was in contrast with Simone *et al.* (2016) who reported increase in Mg^{2+} content in mixed cover crop in Brazil. The % reduction in Mg^{2+} in CCM plots with highest density (16 %) was significantly higher than the lower density (8.92%). The continuous sapping of the nutrients from the same plots by higher plant population could be responsible for the significant reduction at the higher density. However, between 2008 and 2009, the % increase in Mg^{2+} observed in C_1 (100%) was significantly higher than in C_2 plots (16.28%), this is similar to the trend observed for % increase in Ca^{2+}. Increased soil disturbance in C_1 over the years must have led to release of more Mg^{2+} when compared to the unweeded C_2 plots, which was not tilled throughout each experimental year.

Potassium (K^+)

Potassium level was significantly different among treatment in 2008. It ranges from 0.16 in MS_1 to 0.36 in C_1. K in C_1 plots was significantly higher than in other plots. However, K^+ in AM plots, AS plots and AMS plots were higher than in C_2 plots. This reflected on one hand, higher pulverisation which might lead to release of more K^+ in C_1, and less release in C_2 plots with minimal inter-tillage, this was in accordance with the work of Beck *et al*. (2016) who reported decrease K^+ in all cover crops treated plots in over two years field experiment in six summer cover crop treatments in North Carolina. The decomposition and mineralization of cover crops must have added K^+ in such plots when compared to C_2. In 2009, K^+ value ranged between 0.13 in AMS_2 to 0.20 in AM_1. Potassium in most treated plots was higher than in unweeded check C_2. Among the CCM there seems to be significant reduction in K^+ with increased plant densities. Nutrient demand by crops reflects the nature and population of the crops. Sparsely planted crops exact low nutrient pressure when compared with densely planted crops; thus making the soil poorer with higher density as observed in this experiment. In AMS, AM, MS, general decrease in K^+ level was observed in all the treatments except MS_1.

Reduction in %K in C_1 (58.3%) was higher than in AMS (40.9%) though similar with C_2 but higher than K^+ in AS and AM plots, and the least was recorded in MS plots. The higher diversity in AMS must have exacted more nutrient pressure in respect of K^+ over the years when compared to the less diverse system. Percentage K^+ reduction was highest for C_1 (58.33%) when compared to C_2 (38.1%) and other densities (13.46 –27.04%). The possibility of leaching which is likely to be higher in C_1 as a result of bare surface without cover might be responsible for the highest loss/reduction in K^+ over the years in compared with other treatments. The weeds that could have served as complementary cover were removed from time to time leaving the surface bare to the impact of rain droplets. Higher densities of mixed cover crop recorded significantly higher %K reduction when compared with the low density.

Sodium (Na^+)

Sodium (Na^+) significantly differs among the treatment in 2008. Ranging from 0.25-0.38 (AM), 0.23-0.37 (AS), 0.28-0.32 (MS), 0.22-0.38 (AMS) when compared with the control (0.28-0.29). In 2009, Na^+ level range from 0.22 in AS_3 to 0.36 in AM_2. There was a general decrease in Na^+ between 2008 and 2009 in all the treatment except AM_2 and AMS_3. Percentage reduction in Na^+ level was highest in MS plots (25.8%), which was significantly higher than in AS (16.3%), the controls (10.3 – 10.7%) and AMS (9.68%). This showed the possibility of using MS and AS for bioremediation of soils high in sodium, having been able to reduce Na^+ level to about a quarter within a year. The lowest percentage reduction in Na^+ in the AMS reflected the high diversity in such system making it more sustainable, agreed with Sharma *et al.* (2018b); Michael *et al.* (2015), they had earlier reported decrease in Na^+ in cover crop plots. The bare treatment did not show any increase or decrease in Na^+ concentration as compared to the initial values, whereas there were decreases in Na^+ concentration in the sole (31-32%,) and mixed cover crop (29%) treatments respectively (Sharma *et al*. 2018b). The % reduction in Na^+ declines with increasing planting densities. Percentage Na reduction in the low density (19.83%) was higher than in the control plots (10.34 – 10.71%) and higher densities (5.5 – 7.2%), it was evidence that plots with higher plant population utilizes more Na.

Exchangeable Acidity (EA)

The exchangeable acidity (EA) was significantly influenced by cover crops mixture. All the mixed cover crop treated plots recorded lower exchangeable acidity than in C_2 (5.3) when compared to C_1 (3.8) in 2008. In 2009, the highest EA value was equally recorded in C_2 plots. The C_1 plots recorded the least value (1.9) which was significantly less than EA value in all the treated plots. The highest EA value in the unweeded plot reflected the no inter-tillage status and continuous weed cover which significantly reduce leaching of nutrients on one hand, and the binding effect of the roots on the soils when compared with other treatments. The impact of decomposition, mineralization of mixed cover crops in all the treated plots increased EA when compared with the C_1, without cover crop. This confirms the findings of Asadu and Dixon (2006) that observed an increase in total exchangeable acidity in the freshly cultivated forest zone. There was a generally decrease in EA between 2008 and 2009 except in AM_2. These results might be attributed to the sandy loam, lose nature of the soils which was influenced by the cover crop mixture plots. This decreased leaching of exchangeable bases and reduced the erodibility of the soils; thereby lowered the EA (H^+ and Al^{2+}) complex. Furthermore, low EA value could be due to lower clay contents which increased coarse materials hence increasing H^+ content of the soils. Percentage reduction in C_1 was the highest (50%), this was significantly higher than AM (21.88%) and AS (20.14%) plots which were equally higher than in AMS (12.05%) and C_2 (5.66%) plots. These reflected the effect of surface cover and diversity with the highly diverse system being more stable than the two mixed systems. This is in line with the report of Yuan *et al.* (2011) who reported higher reduction in EA in soil treated with leguminous biochar than non-leguminous biochar because the legumes have higher alkalinity and thus neutralized more ex-changeable acidity of the soil. Thus, the higher the diversity, the less the reduction in EA and the more stable the system. The highest reduction of EA in C_1 reflected the impact of rain droplets on the surface which was bare for longer periods thereby reducing cohesion and adhesion of soil particles leaving more sandy soils on the surface. The percentage reduction in EA declined with increasing planting densities. Percentage reduction in EA was highest in C_1 (50%). The order of planting densities followed that of Na^+ above. The lowest plant density (43.42%) caused significantly higher % reduction when compared with the other densities and the unweeded check (1.4 – 16.3%). This is in agreement with Legesse *et al.* (2013) who reported a reduction in EA in a limed soil cultivated with common beans. More diverse systems seem to be more resilient than less diverse ones in respect of Ca^{2+}, Mg^{2+}, Na^+ and EA as observed in this experiment over the years.

pH in water (H_2O)

The pH in water (H_2O) ranged from 6.10 in C_1 to 6.33 (slightly acidic) in AM plots in 2008 (Tables 5 and 6). Plots having higher population of Akidi (AM and AS) seem to have significantly higher pH when compared with other treatments. In 2009, pH ranged from 5.60 in the control plots to 5.77 (both plots were moderately acidic) in AS plots. The presence of akidi, the only leguminous crop in the mixtures seemed to increase the pH values more than other crops. This result might not be unconnected to the ability of akidi to improve soil texture and structure by nitrogen fixation. While the nitrogen is fixed to the soil, the H^+ and Al^{2+} in the soils are reduced. Ferreira *et al*. (2016) reported the number of nitrogen fixation was enhanced under acidic conditions.

All CCM plots except AM, recorded pH that were significantly higher than the control plots. The higher pH level in treated plots when compared with the controls reflected the effect of continual cultivation on the treated plots with uptake of nutrients, further decomposition and mineralization thus increasing the pH. Generally, there was a decrease in pH between 2008 and 2009. The presence of Ca^{2+} in the field might have accounted for the trend of pH (Hao and Chang, 2003).

Plant population did not significantly influenced pH in water. Within each cover crop group, the 30,000 stands /ha recorded higher pH values (AM_2, AS_2 and AMS_2). In 2008, there was increase in pH in MS with increased plant population with the converse in AMS. However, in 2009, there was an increase in pH in AM while decrease in AS and MS with increasing plant population. Percentage reduction in AM plots (13.11%) was higher than the C_2 (9.68%), followed by other CCM groups and C_1 (7.13 - 8.20%). The higher percentage reduction in AM plots reflected low ground coverage and enhanced leaching leading to more acidic soil with reduced pH level. Legesse *et al.* (2013) reported decrease in pH in water after Common Bean Genotypes treatments.

pH in KCl

The pH ranged from 5.30 in AMS_3 to 5.60 in AS_2 and AM_2 plots in 2008 (Tables 5 and 6). As observed in pH (H_2O), similarly higher values were observed in AM and AS plots compared to other treatments. In 2009, pH ranged from 4.90 in AS_3 to 5.40 in C_1 and AS_1 plots. All CCM plots except AS_1, recorded significantly lower pH values than the control plots. Generally, there was a decrease in pH between 2008 and 2009. This trend suggests that leaching and crop essential nutrient take up, increased the acidic condition of the soils when compared to the control treatment. The trend in 2008 was AM/C_2/AS> C_1>MS>AMS, while in 2009, C_1>C_2>AS>MS>AM/AMS. The presence of higher akidi percentage in AM and AS (50%) must have been responsible for the high pH in KCl when compared with plots having low or no leguminous cover crop. In 2008, within the MS plots, an increase in pH was observed with increasing plant population due to higher foliage. This was in agreement with Arévalo-Gardini *et al*. (2015) who reported that soil pH increased due to perennial vegetative cover with abundant foliage, which provides a permanent soil cover and abundant yearly addition of leaf litter that protects the soil from erosion and minimizes the nutrient loss by surface run-off and leaching.

In 2009, MS plots maintained same pH levels irrespective of plant population, however, AS and AMS plots showed decreasing pH levels with increasing plant population. Generally, a decrease in pH was observed with increasing plant population. Higher plant density with consequential higher nutrient demand might cause a decline in pH level. The CCM treated plots had lower pH values irrespective of plant population. The % reduction in pH KCl was highest in AM plots (7.82%) followed by AS (6.73%), then AMS and MS (5.03 - 5.59%) respectively. These were significantly higher than C_2 (3.64%).

Table 3. The effect of cover crop mixtures on Exchangeable cations and Exchangeable Acidity in maize in 2008 and 2009

Treatments	Ca^{2+} cmol kg^{-1}			Mg^{2+} cmol kg^{-1}			K^{+} cmol kg^{-1}			Na^{+} cmol kg^{-1}			Exch. Acidity		
	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓
AM_1	3.20	2.12	-33.75	0.49	0.36	-26.53	0.22	0.20	-9.09	0.38	0.34	-10.53	3.30	2.80	-15.15
AM_2	2.17	2.24	3.23	0.34	0.38	11.76	0.23	0.18	-21.74	0.25	0.36	44.00	4.50	3.00	-33.33
AM_3	2.75	1.80	-34.55	0.42	0.32	-23.81	0.21	0.18	-14.29	0.36	0.35	-2.78	4.00	3.40	-15.00
AM	2.71	2.05	-24.35	0.42	0.35	-16.67	0.22	0.19	-13.64	0.33	0.35	6.06	3.93	3.07	-21.88
AS_1	2.94	2.57	-12.59	0.44	0.37	-15.91	0.23	0.18	-21.74	0.33	0.27	-18.18	4.60	3.80	-17.39
AS_2	2.67	1.99	-25.47	0.46	0.37	-19.57	0.21	0.19	-9.52	0.37	0.28	-24.32	4.10	3.40	-17.07
AS_3	1.82	1.34	-26.37	0.28	0.21	-25.00	0.21	0.16	-23.81	0.23	0.22	-4.35	3.80	2.80	-26.32
AS	2.48	1.97	-20.56	0.39	0.32	-17.95	0.22	0.18	-18.18	0.31	0.26	-16.13	4.17	3.33	-20.14
MS_1	1.97	2.21	12.18	0.32	0.42	31.25	0.16	0.18	12.50	0.32	0.26	-18.75	2.90	2.80	-3.45
MS_2	2.58	2.35	-8.91	0.47	0.49	4.26	0.22	0.18	-18.18	0.32	0.24	-25.00	2.40	4.00	66.67
MS_3	2.24	1.26	-43.75	0.32	0.23	-28.13	0.17	0.14	-17.65	0.28	0.18	-35.71	3.40	2.30	-32.35
MS	2.26	1.94	-14.16	0.37	0.38	2.70	0.18	0.17	-5.56	0.31	0.23	-25.81	2.90	3.03	4.48
AMS_1	2.60	1.50	-42.31	0.41	0.36	-12.20	0.22	0.16	-27.27	0.38	0.26	-31.58	5.80	3.50	-39.66
AMS_2	2.40	1.46	-39.17	0.39	0.36	-7.69	0.27	0.13	-51.85	0.33	0.30	-9.09	3.60	4.00	11.11
AMS_3	2.00	2.69	34.50	0.28	0.33	17.86	0.18	0.10	-44.44	0.22	0.28	27.27	2.30	2.80	21.74
AMS	2.33	1.88	-19.31	0.36	0.35	-2.78	0.22	0.13	-40.91	0.31	0.28	-9.68	3.90	3.43	-12.05
C_1	2.12	4.07	91.98	0.29	0.58	100.00	0.36	0.15	-58.33	0.29	0.26	-10.34	3.80	1.90	-50.00
C_2	2.36	3.01	27.54	0.43	0.50	16.28	0.21	0.13	-38.10	0.28	0.25	-10.71	5.30	5.00	-5.66
Mean	2.42	2.19	-9.50	0.38	0.38	0.00	0.22	0.16	-27.27	0.31	0.27	-12.90	4.29	3.25	-24.24
S.E.M.	0.106	0.202	8.82	0.020	0.026	7.93	0.013	0.008	4.58	0.014	0.013	5.13	0.451	0.212	6.83

AM = Akidi + Melon, AS =Akidi + Sweet potato, MS = Melon + Sweet potato, AMS = Akidi + Melon + Sweet potato, C_1=weeded control, C_2=unweeded control, 1 = 20,000 stands ha^{-1}, 2 = 30,000 stands ha^{-1}, 3 = 40,000 stands ha^{-1}

Table 4. The effect of planting density of cover crop mixtures on Exchangeable cations and Exchangeable Acidity in maize in 2008 and 2009

Treatments	Ca^{2+} cmol kg^{-1}			Mg^{2+} cmol kg^{-1}			K^{+} cmol kg^{-1}			Na^{+} cmol kg^{-1}			Exch. Acidity		
	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓
1	2.678	2.100	-21.58	0.415	0.378	-8.92	0.208	0.180	-13.46	0.353	0.283	-19.83	5.700	3.225	-43.42
2	2.455	2.010	-18.13	0.415	0.400	-3.61	0.233	0.170	-27.04	0.318	0.295	-7.23	3.650	3.600	-1.37
3	2.203	1.773	-19.52	0.325	0.273	-16.00	0.193	0.145	-24.87	0.273	0.258	-5.49	3.375	2.825	-16.30
C_1	2.12	4.07	91.98	0.29	0.58	100.00	0.36	0.15	-58.33	0.29	0.26	-10.34	3.80	1.90	-50.00
C_2	2.36	3.01	27.54	0.43	0.50	16.28	0.21	0.13	-38.10	0.28	0.25	-10.71	5.30	5.00	-5.66
Mean	2.42	2.19	-9.50	0.38	0.38	0.00	0.22	0.16	-27.27	0.31	0.27	-12.90	4.29	3.25	-24.24
S.E.M.	0.106	0.202	8.82	0.020	0.026	7.93	0.013	0.008	4.58	0.014	0.013	5.13	0.451	0.212	6.83

C_1=weeded control, C_2=unweeded control, 1 = 20,000 stands ha^{-1}, 2 = 30,000 stands ha^{-1}, 3 = 40,000 stands ha^{-1}

Table 5. The effect of cover crop mixtures on soil pH, Organic Carbon, Total Nitrogen and Available Phosphorus in maize in 2008 and 2009

Treatments	pH (H_2O)			pH (KCl)			O.C g kg^{-1}			N g kg^{-1}			AV-P mg kg^{-1}		
	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓
AM_1	6.30	5.40	-14.29	5.40	5.10	-5.56	5.67	11.54	103.53	0.59	1.20	103.39	4.44	0.55	-87.61
AM_2	6.40	5.40	-15.63	5.60	5.00	-10.71	7.49	7.04	-6.01	0.78	0.73	-6.41	8.51	0.97	-88.60
AM_3	6.30	5.70	-9.52	5.50	5.10	-7.27	12.56	8.61	-31.45	1.30	0.89	-31.54	2.77	0.14	-94.95
AM	**6.33**	**5.50**	**-13.11**	**5.50**	**5.07**	**-7.82**	**8.57**	**9.06**	**5.72**	**0.89**	**0.94**	**5.62**	**5.24**	**0.55**	**-89.50**
AS_1	6.20	5.90	-4.84	5.50	5.40	-1.82	10.94	10.95	0.09	1.13	1.14	0.88	6.65	1.52	-77.14
AS_2	6.30	5.70	-9.52	5.60	5.10	-8.93	7.49	6.23	-16.82	0.78	0.65	-16.67	3.60	0.14	-96.11
AS_3	6.20	5.70	-8.06	5.40	4.90	-9.26	5.87	7.19	22.49	0.61	0.95	55.74	3.33	0.69	-79.28
AS	**6.27**	**5.77**	**-7.97**	**5.50**	**5.13**	**-6.73**	**8.10**	**8.12**	**0.25**	**0.84**	**0.91**	**8.33**	**4.53**	**0.78**	**-82.78**
MS_1	6.10	5.70	-6.56	5.30	5.10	-3.77	4.25	4.89	15.06	0.44	0.51	15.91	3.74	1.80	-51.87
MS_2	6.10	5.70	-6.56	5.40	5.10	-5.56	5.67	7.82	37.92	0.59	0.81	37.29	5.13	0.97	-81.09
MS_3	6.20	5.60	-9.68	5.40	5.10	-5.56	9.32	6.85	-26.50	0.97	0.71	-26.80	3.05	0.69	-77.38
MS	**6.13**	**5.67**	**-7.50**	**5.37**	**5.10**	**-5.03**	**6.41**	**6.52**	**1.72**	**0.67**	**0.68**	**1.49**	**3.97**	**1.15**	**-71.03**
AMS_1	6.20	5.60	-9.68	5.40	5.10	-5.56	7.90	7.70	-2.53	0.82	0.80	-2.44	3.74	1.39	-62.83
AMS_2	6.20	6.20	0.00	5.40	5.10	-5.56	3.65	7.63	109.04	0.38	0.79	107.89	3.19	2.08	-34.80
AMS_3	6.10	5.40	-11.48	5.30	5.00	-5.66	7.09	8.99	26.80	0.74	0.93	25.68	2.36	0.28	-88.14
AMS	**6.17**	**5.73**	**-7.13**	**5.37**	**5.07**	**-5.59**	**6.21**	**8.11**	**30.60**	**0.65**	**0.84**	**29.23**	**3.10**	**1.25**	**-59.68**
C_1	6.10	5.60	-8.20	5.40	5.40	0.00	7.70	12.32	60.00	0.80	1.28	60.00	3.19	8.03	151.72
C_2	6.20	5.60	-9.68	5.50	5.30	-3.64	8.30	10.37	24.94	0.86	1.08	25.58	3.05	2.49	-18.36
Mean	6.21	5.66	-8.86	5.44	5.13	-5.70	7.42	8.44	13.75	0.77	0.89	15.58	4.05	1.55	-61.73
S.E.M.	0.025	0.056	0.92	0.025	0.038	0.67	0.648	0.575	10.10	0.067	0.059	10.23	0.450	0.534	14.78

AM = Akidi + Melon, AS =Akidi + Sweet potato, MS = Melon + Sweet potato, AMS = Akidi + Melon + Sweet potato, C_1=weeded control, C_2=unweeded control, 1 = 20,000 stands ha^{-1}, 2 = 30,000 stands ha^{-1}, 3 = 40,000 stands ha^{-1}

The % reduction in pH KCl was in the order AM>AS>AMS/MS>C_2. This reflected the amount of soil cover and diversity. Poor soil cover leads to higher percentage reduction observed in AM plots when compared with other treatments and C_2. The higher diverse AMS seem to be more resilient to change in pH KCl, similar to what was obtained in pH (H_2O) and thus, fluctuation in soil pH level could be minimized by increasing crop diversity.

Organic carbon (OC)

In 2008, the OC content ranged from 3.65 to 12.56 g kg^{-1} in AMS_2 and AM_3 respectively (Tables 5 and 6). Within AM and MS plots, a decrease in OC content with increasing plant population was observed, while AS plot recorded increase with increasing plant population. The trend followed AM> C_2>AS>C_1>MS>AMS. Decomposition rate which is a function of C/N ratio as well as deposition rate affects soil OC at any given point in time. AM with lower C/N decomposes faster than MS and AS, leading to higher OC in 2008. Labile constituents of crop residues are used more efficiently by the soil microbial population, generating microbial products responsible for soil aggregation and stabilization of soil organic matter (SOM) through strong connections with the soil mineral matrix (Cotrufo *et al*., 2013). In 2009, the OC content ranged from 4.89 to 12.32 g kg^{-1} in MS_1 and C_1 respectively. All CCM treated plots recorded significantly lower OC values than C_1. The trend followed C_1>AM>C_2>AS>AMS>MS. The C_1 and C_2 plots had higher OC contents than CCM plots irrespective of plant population. This reflected the higher nutrient demand of all the cover crop mixtures which exacted more on the soils when compared with the controls.

Generally, there was an increase in OC content between 2008 and 2009. The % increase was in the order; C_1>AMS/C_2>AM/AS/MS. An increase in soil organic C concentration is positively correlated with an increase in soil aggregate stability (Blanco-Canqui *et al.,* 2013).

Soil cover crops have numerous benefits mainly under no-till system, such as preventing soil erosion, increasing soil C stocks (Amado *et al*., 2006; Bayer *et al*., 2009), nutrient cycling (Tiecher *et al*., 2017). The more diverse AMS with varied and prolonged duration, rate of decomposition and mineralization might build up soil OC over time when compared with other treated plots. Sharma *et al*. (2018a) observed that the inclusion of continuous cover cropping resulted in small increases of organic C and total N only in the top 0 to 5 cm soil depth in the mixed cover crop treatment. Both C and N concentration in the topsoil (0 to 5 cm) mixed cover crop plots had increased by 8% and 21% respectively, and in the sole cover crop plots by 10% and 5% respectively.

Total Nitrogen (TN)

In 2008, TN ranged from 0.38 to 1.30 g kg^{-1} in AMS_2 and AM_3 respectively (Tables 5 and 6). All CCM plots and the control plots were rated low for soil TN according to critical soil ratings by Babalola *et al* (1998). Within AM and MS plots, there was increase TN with increase plant population, while decrease in TN with increasing plant population was noticed in AS plots. Though akidi fixes nitrogen, the demand for N could not be met at higher population, hence the decrease. The amount required by associated crop could be fully met by N release of summer legumes if it is higher than the demand of the associated crop (Weiler *et al*., 2019). The trend followed AM>C_2>AS>C_1>MS>AMS. However, in 2009, there was a general increase in TN, and values ranged from 0.51 to 1.28 g kg^{-1} in MS_1 and C_1 respectively. All CCM plots, except AM had significantly lower TN contents than C_1 plot. The trend followed C_1>C_2>AM>AS>AMS>MS. Under the same environmental conditions, crop residues differ in decomposition and N release basically due to chemical composition and all treatments with legume resulted in higher N (Trinsoutrot *et al*., 2000; Redin *et al*., 2014).

The C_1 and C_2 plots had higher TN contents than the CCM plots irrespective of plant population. Demand for N was higher for treated plots than the controls. This is contrary to Mubiru and Coyne (2009) who reported that all improved fallows produced significantly more N than the natural fallow. The nitrogen fixing ability of leguminous akidi (AM and AS) is also implicated when compared with other treatments with low or no akidi (AMS and MS). The % increase in TN in C_1 (60%) was significantly higher than AMS (29.23%) and C_2 plots (25.58%), which were higher the rest CCM plots (1.49 – 8.33%). The low utilization of TN in control plots and higher diversity in AMS makes more N to be retained in the soils when compared to other treatments. Mixing crops of distinct families as in AMS has been tested by research and could result in intermediate C:N ratio and combine N input and soil protection (Heinrichs *et al*., 2001; Doneda *et al*., 2012). Initial rapid decomposition was also favoured by the low C:N ratio of the cover crops, which was the major determinate of the rate of decomposition (Trinsoutrot *et al*. 2000; Redin *et al*. 2014).

Available P

In 2008, available P content ranged from 2.36 to 8.51 mg kg^{-1} in AMS_3 and AM_2 respectively (Tables 5 and 6). All plots regardless of crop cover mixtures or control were rated low (0 -10 mg kg^{-1}) for soil AV-P. Within AMS and AS plots, AV-P decreased with increasing plant population. The trend followed AM>AS>MS>C_1>AMS>C_2. This is in line with Mubiru and Coyne (2009) who reported that leguminous Canavalia accumulated significantly more P than other fallows.

However, in 2009, there was general decrease in AV-P compared to 2008, with values ranging from 0.14 (AMS and AS_2) to 8.03 mg kg^{-1} in C_1. Within MS plots, decrease in AV-P content was observed with increasing plant population. The AV-P in C_1 plot was significantly higher than in other treatments. The trend followed $C_1 >> C_2 >$AMS>MS>AS>AM. The C_1 and C_2 plots recorded higher AV-P content than CCM plots irrespective of plant population. Generally, there was a decrease in AV-P with increased plant population. This reflected higher P demand with increasing population. The % reduction in AV-P was highest in AM (89.5%), though similar with AS plots (82.78%); was significantly higher than the rest CCM plots and C_2 (18.36 – 71.3%), while an increase in AV-P was only observed in C_1 plot (151.72%) respectively. The % reduction in AV-P was in the order, AM/AS>MS>AMS>C_2. The AV-P content of the soils which seemed adequate for AM and AS in 2008 must have been grossly depleted over the years. Thus, any system where leguminous akidi will be used may require supplemental P. Phosphorus is known as a major limiting factor in leguminous production. More diverse AMS system and less disturbed C_2 seem to be more resilient with minimal loss of P. The observed increase in the highly pulverised C_1 plot could be due to enhanced mobilization as a result of more frequent inter-tillage activity. Weerasekara *et al*. (2017) observed that C, N, and P contents decreased with time in all soil types, possibly due to uptake of nutrients by the cover crops.

Effective Cation exchange capacity (ECEC)

In 2008, ECEC values ranged from 6.0 to 11.86 cmol kg^{-1} in MS_2 and MS_1 respectively (Tables 7 and 8). The ECEC of the soils for all the plots in 2008 and 2009 were rated low (<6 cmol kg^{-1}) to medium (6-12 cmol kg^{-1}). Within AS, MS and AMS plots, ECEC values were observed to decrease with increasing plant population. Higher plant densities increase soil mining thereby reducing the soil available nutrients and ECEC. However, in 2009, ECEC values ranged from 4.12 cmol kg^{-1} in MS_3 to 8.89 cmol kg^{-1} in C_2 plots. Within AS plots, ECEC decreased with increasing plant population. All CCM plots had significantly lower values than C_2. The ECEC in all the CCM treated plots is an indication of higher nutrient demand and decline in cations in those plots as they were taken up by the crop unlike in the unweeded check C_2, where nutrient uptake is expected to be less. This is in contrast with Degu *et al*. (2019) that rotation with legume recorded highest pH, ECEC and total nitrogen because of continuous deposits of sediments Generally, there was decrease in ECEC from 2008 to 2009. This is in contrast with Hulugalle (1988) who reported that total ECEC, soil N, Bray-l-P, and total porosity were not significantly affected by cover crop. Soil ameliorative ability of cover crop was primarily related to rapidity of formation of ground cover and subsoil root density.

There was general decrease in ECEC from 2008 to 2009 in CCM treated plots. The C_2 had higher ECEC values than all other treatments in 2008 and 2009. The % decline in ECEC over the years was in the order, MS>AM/AS>AMS. This showed the resilience of a more diverse system (AMS) in curtailing and maintaining soil ECEC. The controls (1.46 - 3.61%) recorded marginal % increase that were not significantly different and the results agreed with earlier work of Legesse *et al.* (2013).

Change in soil physical properties

% Silt and Clay

In 2008, % silt and clay ranged from 14.80% (C_1, C_2 and MS_1 plots) to 20.80% in AS_2 plot (Tables 7 and 8). Within MS plots, there was increase in % silt and clay with increasing plant population, while the converse was observed in AMS plots. The C_1 and C_2 plots recorded significantly lower % silt and clay than CCM plots except MS_1. The CCM plots reflected higher aggregate stability as compared to the controls. Seven out of 11 studies found that CCs increased wet aggregate stability, while four found no effects. Cover crops increase aggregate stability by protecting the soil surface from raindrop impact, providing additional biomass input (i.e., roots), and increasing soil organic C concentration and microbial activity (Blanco-Canqui *et al*., 2015).

This is in contrast with Hulugalle (1988) who reported that sand and silt contents were not significantly affected by cover crop. The low silt and clay content is typical of sandy loam soils where fine or coarse sand predominates the soils especially at the epipedons.

In 2009, % silt and clay ranged from 13.40 to 20.80 in MS_3 and AM_1 respectively. Within AM, MS, and AMS plots, % silt and clay decreased with increasing plant population, the % silt and clay remained stable irrespective of plant population in AS plots. The increased population lead to increase in adsorption, absorption and utilization of soil nutrients with commensurate decrease in % silt and clay. The roots' penetration disintegrates soil particles and tend to increase sand content. The C_2 plot recorded significantly higher value than other treatments except AM_1 and AMS_1 plots. The demand for nutrient over the years could not be sustained by the nutrient supplied from the crops cultivated, thus, the observed reduction in the % silt and clay. Furthermore, surface runoff might have reduced clay and silt fractions by erosion of the years and reduced fine particles and more coarse sand on the soil surface.

Table 6. The effect of planting density of cover crop mixtures on soil pH, Organic Carbon, Total Nitrogen and Available Phosphorus in maize in 2008 and 2009

Treatments	pH (H_2O)			pH (KCl)			O.C g kg^{-1}			N g kg^{-1}			AV-P mg kg^{-1}		
	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓
1	6.200	5.650	-8.87	5.400	5.175	-4.17	7.190	8.770	21.97	0.745	0.913	22.55	4.643	1.315	-71.68
2	6.250	5.750	-8.00	5.500	5.075	-7.73	6.075	7.180	18.19	0.633	0.745	17.69	5.108	1.040	-79.64
3	6.200	5.600	-9.68	5.400	5.025	-6.94	8.710	7.910	-9.18	0.905	0.870	-3.87	2.878	0.450	-84.36
C_1	6.10	5.60	-8.20	5.40	5.40	0.00	7.70	12.32	60.00	0.80	1.28	60.00	3.19	8.03	151.72
C_2	6.20	5.60	-9.68	5.50	5.30	-3.64	8.30	10.37	24.94	0.86	1.08	25.58	3.05	2.49	-18.36
Mean	6.21	5.66	-8.86	5.44	5.13	-5.70	7.42	8.44	13.75	0.77	0.89	15.58	4.05	1.55	-61.73
S.E.M	0.025	0.056	0.92	0.025	0.038	0.67	0.648	0.575	10.10	0.067	0.059	10.23	0.450	0.534	14.78

C_1=weeded control, C_2=unweeded control, 1 = 20,000 stands ha^{-1}, 2 = 30,000 stands ha^{-1}, 3 = 40,000 stands ha^{-1}

Table 7. The effect of cover crop mixtures on effective Cation Exchange Capacity, % silt and clay, % clay, % silt and % fine sand in maize in 2008 and 2009

Treatments	ECEC (cmol kg^{-1})			% Silt and Clay			% Clay			% Silt			% Fine Sand		
	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓
AM_1	7.59	5.82	-23.32	16.80	20.80	23.81	3.40	9.40	176.47	13.40	11.40	-14.93	83.20	79.20	-4.81
AM_2	7.48	6.16	-17.65	18.80	16.80	-10.64	5.40	4.00	-25.93	13.40	12.80	-4.48	81.20	83.20	2.46
AM_3	7.75	6.05	-21.94	16.80	16.80	0.00	5.40	6.00	11.11	11.40	10.80	-5.26	83.20	83.20	0.00
AM	**7.61**	**6.01**	**-21.02**	**17.47**	**18.13**	**3.78**	**4.73**	**6.47**	**36.79**	**12.73**	**11.67**	**-8.33**	**82.53**	**81.87**	**-0.80**
AS_1	8.53	7.19	-15.71	18.80	14.80	-21.28	3.40	6.00	76.47	16.40	8.80	-46.34	81.20	85.20	4.93
AS_2	7.81	6.22	-20.36	20.80	14.80	-28.85	7.40	6.00	-18.92	13.40	8.80	-34.33	79.20	85.20	7.58
AS_3	6.34	4.73	-25.39	18.80	14.80	-21.28	3.40	6.00	76.47	15.40	8.80	-42.86	81.20	85.20	4.93
AS	**7.56**	**6.05**	**-19.97**	**19.47**	**14.80**	**-23.99**	**4.73**	**6.00**	**26.85**	**15.07**	**8.80**	**-41.61**	**80.53**	**85.20**	**5.80**
MS_1	11.86	5.86	-50.59	14.80	17.40	17.57	5.40	6.00	11.11	9.40	11.40	21.28	85.20	82.60	-3.05
MS_2	6.00	7.19	19.83	16.80	17.40	3.57	5.70	4.00	-29.82	11.40	13.40	17.54	83.20	82.60	-0.72
MS_3	6.41	4.12	-35.73	16.80	13.40	-20.24	5.70	6.00	5.26	11.40	7.40	-35.09	83.20	86.60	4.09
MS	**8.09**	**5.72**	**-29.30**	**16.13**	**16.07**	**-0.37**	**5.60**	**5.33**	**-4.82**	**10.73**	**10.73**	**0.00**	**83.87**	**83.93**	**0.07**
AMS_1	9.41	5.77	-38.68	18.80	18.80	0.00	5.70	5.40	-5.26	13.40	13.40	0.00	81.20	81.20	0.00
AMS_2	6.99	6.24	-10.73	18.80	14.80	-21.28	5.70	5.40	-5.26	13.40	9.40	-29.85	81.20	85.20	4.93
AMS_3	4.98	6.20	24.50	16.80	14.80	-11.90	5.40	7.40	37.04	11.40	7.40	-35.09	83.20	85.20	2.40
AMS	**7.13**	**6.07**	**-14.87**	**18.13**	**16.13**	**-11.03**	**5.60**	**6.07**	**8.39**	**12.73**	**10.07**	**-20.90**	**81.87**	**83.87**	**2.44**
C_1	6.86	6.96	1.46	14.80	14.80	0.00	3.40	5.40	58.82	11.40	9.40	-17.54	85.20	85.20	0.00
C_2	8.58	8.89	3.61	14.80	18.80	27.03	3.40	5.40	58.82	11.40	13.40	17.54	85.20	81.20	-4.69
Mean	7.61	6.25	-17.87	17.37	16.36	-5.81	4.91	5.89	19.96	12.61	10.47	-16.97	82.63	83.64	1.22
S.E.M.	0.449	0.303	4.94	0.488	0.562	4.31	0.340	0.354	12.91	0.494	0.586	5.65	0.488	0.562	0.93

AM = Akidi + Melon, AS =Akidi + Sweet potato, MS = Melon + Sweet potato, AMS = Akidi + Melon + Sweet potato, C_1=weeded control, C_2=unweeded control, 1 = 20,000 stands ha^{-1}, 2 = 30,000 stands ha^{-1}, 3 = 40,000 stands ha^{-1}

Table 8. The effect of planting density of cover crop mixtures on Cation Exchange Capacity, % silt and clay, % clay, % silt and % fine sand in maize in 2008 and 2009

Treatments	ECEC (cmol kg^{-1})			% Silt and Clay			% Clay			% Silt			% Fine Sand		
	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓	2008	2009	% ↑↓
1	9.348	6.160	-34.10	17.300	17.950	3.76	4.475	6.700	49.72	13.150	11.250	-14.45	82.700	82.050	-0.79
2	7.070	6.453	-8.73	18.800	15.950	-15.16	6.050	4.850	-19.83	12.900	11.100	-13.95	81.200	84.050	3.51
3	6.370	5.275	-17.19	17.300	14.950	-13.58	4.975	6.350	27.64	12.400	8.600	-30.65	82.700	85.050	2.84
C_1	6.86	6.96	1.46	14.80	14.80	0.00	3.40	5.40	58.82	11.40	9.40	-17.54	85.20	85.20	0.00
C_2	8.58	8.89	3.61	14.80	18.80	27.03	3.40	5.40	58.82	11.40	13.40	17.54	85.20	81.20	-4.69
Mean	7.61	6.25	-17.87	17.37	16.36	-5.81	4.91	5.89	19.96	12.61	10.47	-16.97	82.63	83.64	1.22
S.E.M	0.449	0.303	4.94	0.488	0.562	4.31	0.340	0.354	12.91	0.494	0.586	5.65	0.488	0.562	0.93

C_1=weeded control, C_2=unweeded control, 1 = 20,000 stands ha^{-1}, 2 = 30,000 stands ha^{-1}, 3 = 40,000 stands ha^{-1}

Table 9. Yield of maize, Akidi and Sweet potato

Treatment	Maize Grain yield (kg ha^{-1})			Grain yield of akidi (kg ha^{-1})			Fresh tuber yield of sweet potato (kg ha^{-1})		
	2008	2009	Average	2008	2009	Average	2008	2009	Average
AM_1	2027.9ab	2676.1ab	2352.0ab	136.0a	25.8e	80.9b			
AM_2	2698.0a	2523.9ab	2611.0a	116.0a	9.0g	62.5c			
AM_3	3293.7a	1948.1ab	2620.9a	177.2a	57.0c	117.1a			
AM	**2673.2a**	**2382.7ab**	**2528.0ab**	**143.1a**	**30.6de**	**86.8b**			
AS_1	2462.0ab	2355.7ab	2408.9ab	79.7a	153.4b	116.6a	883.3c	3778a	2330.7c
AS_2	2577.9ab	1466.7b	2022.3ab	104.2a	213.5a	158.9a	1683.3bc	16167a	8925.2a
AS_3	2073.3ab	1263.5b	1668.4b	120.6a	210.1a	165.4a	3344.4abc	14222a	8783.2a
AS	**2371.1ab**	**1695.3b**	**2033.2ab**	**101.5a**	**192.3ab**	**146.9a**	**1970.3bc**	**11389.0a**	**6679.7a**
MS_1	2412.4ab	2028.5ab	2220.5ab				1444.4bc	5556a	3500.2ab
MS_2	2578.0ab	2333.3ab	2455.7ab				5708.3a	14833a	10270.7a
MS_3	2578.0ab	1282.8b	1930.4ab				3819.4ab	6444a	5131.7ab
MS	**2522.8ab**	**1881.5ab**	**2202.2ab**				**3657.4ab**	**8944.3a**	**6300.9a**
AMS_1	2387.6ab	1971.5ab	2179.6ab	76.4a	13.0f	44.7d	3027.7abc	2356a	2691.9bc
AMS_2	2184.0ab	2339.2ab	2261.6ab	74.1a	26.0e	50.1cd	3527.8abc	4550a	4038.9ab
AMS_3	1909.7ab	2000.0ab	1954.9ab	84.5a	31.2d	57.9c	2999.9abc	10111a	6555.5a
AMS	**2160.4ab**	**2103.6ab**	**2132.0ab**	**78.3a**	**23.4e**	**50.9cd**	**3185.1abc**	**5672.3a**	**4428.7ab**
C_1	3271.3a	3666.7a	3469.0a						
C_2	875.2b	864.0b	869.6b						

AM = Akidi + Melon, AS =Akidi + Sweet potato, MS = Melon + Sweet potato, AMS = Akidi + Melon + Sweet potato, C_1=weeded control, C_2=unweeded control, 1 = 20,000 stands ha^{-1}, 2 = 30,000 stands ha^{-1}, 3 = 40,000 stands ha^{-1}

There was a general decrease in % silt and clay from 2008 to 2009, except in C_2, AM and C_1 plots. The percentage decline in % silt and clay were highest in AS plots (23.99%) followed by AMS (11.03%) and MS (0.37%). This indicates higher nutrient demand by aggressive akidi and near perennial sweet potato crop, both at high densities when compared to other treatments with low or no akidi or sweet potato. However, there was percentage increase in % silt and clay in C_2 (27.03%) and AM plots (3.78%).

% Clay

In 2008, % clay ranged from 3.40% (C_1, C_2, AM_1, AS_1 and AS_3 plots) to 7.40% in AS_2 plots (Tables 7 and 8). Within AM and MS plots, there was an increase in % clay with increasing plant population. In 2009, % clay ranged from 4.0 (AM_2 and MS_2) to 9.40 in AM_1. Within AMS plots, there was an increase in % clay with increasing plant population, while AS plots maintained same values irrespective of plant population. The increase in % clay observed with increasing plant population is an indication that more organic matter produced must have enhanced the binding capacity of the soils. The potential of biomass production of these species may be even higher when grown at higher plant population, even in a relatively short period (Weiler *et al.*, 2019), due to vigorous growth and high capacity of legumes to fix N_2 in symbiosis with diazotrophic bacteria (Aita and Giacomini, 2003). This is confirmed in higher percentage clay in plots with higher akidi, the leguminous cover crop. Degu *et al*. (2019) reported that rotation with legume reported that clay content in conserved system is greater than unconserved system because of continuous deposits of sediments. In 2008, 30,000 stands ha^{-1} recorded highest % clay values, while 20,000 stands ha^{-1} was highest in 2009. This shows that significant increase in % clay can be observed at higher plant population. This similar to the findings of Hulugalle (1988) who reported significant increase in clay content following cover crop treatment. The percentage increase in % clay which was highest in the controls (58.82%) was significantly higher than in AM (36.79%) and AS plots (26.85%), while the least percentage increase was observed in AMS plots (8.39%). This general increase over the years in most CCM plots supports the findings of in their evaluation of impact of cover crops on soil in two maize farms Mahama *et al.* (2016) observed an increase in % clay after two growing seasons. High diversity seems to moderate changes in soil properties including % clay content over the years, hence its marginal increase when compared with the less diverse system. However, percentage decline in % clay was recorded in MS plots (4.82%). Melon and sweet potato which are said to be less compatible produced little impact on improving the clay content. The order C_1/C_2>AM/AS/>AMS was observed.

% Silt

In 2008, % silt ranged from 9.40 to 16.40% in MS_1 and AS_1 respectively (Tables 7 and 8). Within MS plot, % silt was observed to increase with increasing plant population while the converse was observed in AM and AMS plots.
In 2009, % silt ranged from 7.40 (MS_3 and AM_3) to 13.40 (MS_2, AMS_1 and C_2). Within AMS plots, % silt decreased with increasing plant population, while it remained constant in AS plots irrespective of plant population. The C_2 plot did not significantly differ in % silt from AMS_1, MS_2 and AM_2. Hulugalle (1988) reported that silt content was not significantly affected by preceding cover crop in Burkina Faso.

There was general decrease in % silt from 2008 to 2009, except for MS and C_2 treatment. The decline in % silt was in the order AS>AMS>AM. However, % silt increased in C_2 (17.54%) over the years. The higher percentage reduction in silt observed in AS could be as a result of the combined higher demand of akidi and sweet potato for nutrient on the soil when compared with other treatments that are less aggressive because of the presence of melon with minimal nutrient demand. This supports the findings of Mahama *et al.* (2016) who reported decrease in % silt (55 to 49% and 39 to 38% respectively) in two maize farms planted with cover crops over two growing seasons. Michael *et al*. (2015) in their evaluation of sole planted akidi, melon or sweet potato in association with maize on soil physico-chemical properties observed that there was a decline in the silt proportion; but fine sand increased in all the treatments over the years. The increased percentage silt in C_2 indicate low inter-tillage and higher build-up of soil structure over the years in a rarely disturbed plot. There was no significant difference in percentage silt reduction between the weeded control and lower densities of the mixed cover crops. This supports the findings of Acuna (2013) who reported that winter cover crops did not differ from the control in improving soil physical properties in two locations in the US.

% Fine Sand

In 2008, % fine sand ranged from 79.20 in AS_2 to 85.20 (MS_1, C_1 and C_2) (Tables 7 and 8). Within MS plots, a decrease in % fine sand was observed with increasing plant population, while the converse was observed in AMS plots. The C_1 and C_2 plots recorded higher values than CCM treated plots except MS_1. This shows higher aggregate stability in CCM than the controls. In the evaluation of cover crop on soil properties in Turkey, the cover crop treatments significantly increased aggregate stability compared to the bare control in two years. The cover crop treatments significantly increased soil aggregate stability from 62.2% in the herbicide treatment to 67.3% in the *Vicia* treatment in the second year of the experiments (Demir and Işık, 2019). In 2009, % fine sand ranged from 79.20 in AM_1 to 86.60 in MS_2. Within AM plots, there was an increase in % fine sand with increasing plant population, whereas a decrease in % fine sand was observed in AMS plots. In 2008, 30,000 stands/ha recorded the lowest % fine sand. In 2009, increasing % fine sand was observed as plant population increased. There was general increase in % fine sand in CCM treated plots except AM plots. The increase in % fine sand over the years is probably due to reduction in the silt content and nutrient on one hand and the shattering effect of the roots on the soil particles on the other hand, thus, making akidi and sweet potato plots to have the highest increase in % fine sand. Michael *et al*. (2015) in their evaluation of sole planted cover crops in association with maize on soil physico-chemical properties observed that fine sand increased in all the treatments over the years. This is confirmed in the present study. The decrease in % fine sand in C_2 is just a reflection of the high silt content with higher binding effect of the undisturbed plot. This is contrary to the findings of Hulugalle (1988) and Seguel *et al.* (2013) who reported that sand content was not significantly affected by preceding cover crop. Higher density resulting in higher % fine sand just reflected the higher root impact on the soil aggregates when compared with the low plant density. Increase in % fine sand was in the order AS>AMS>MS, whereas % fine sand decreased in C_2 (4.69%). This supports the findings of Mahama *et al*. (2016) who reported an increase in sand from 14 to 18% on one hand, and a decrease in % sand (from 54 to 51%) in two different locations in the US with initial low and moderate % sand respectively after growing cover crops over two seasons.

Yield of maize and cover crops

Increasing plant populations in AM increased maize grain yield (MGY), but AS decreased MGY as the planting density increased. In 2008, there were no significant differences in MGY among the CCM treated plots, they were comparable to C_1. In 2009, MGY in AS_2 and AS_3 and C_2 were significantly ($p<0.05$) lower than that which was obtained in C_1 plot. This is in agreement with Krstić *et al*. (2018) who reported reduced yield of the accompanying crop due to reduction in soil water storage by cover crop treatments especially during dry year. Averaged over the two years, the order AM >MS> AMS>AS was observed in the MGY. Highest maize grain yield was recorded in C_1 (3469 kg ha^{-1}), which was not significantly different from AM_3 (2620.9 kg ha^{-1}), AM_2 (2611 kg ha^{-1}). Others, though higher in MGY than C_2, there was no significant difference. The MGY yield in AM treated plots increases with plant population, but decreases in AS and MS treated plots. The effect of the cover crop mixtures involving akidi on maize grain yield, suggested that the presence of akidi in any treatment had a depressing effect on yield as observed in 2009 as in other crops like cocoyam (Nwagwu *et. al,* 2000). Melon as a short-cycled crop dies early in the season, introduce some nutrient to the soil and more space was available for remaining crops to utilize resources at the maturity phase. It thus become logical to have higher yield in combinations having melon. This could explain the significantly ($p<0.05$) higher MGY in AM and MS plots. The yield of cover crop reflected the plant population to a large extent. Plots with higher populations of akidi or and sweet potato resulted in higher yields and this was in line with earlier finding of Tijani-Eniola and Akinnifesi (1998).

Conclusion

The effects of a leguminous cover crop, Akidi (A), *Vigna unquiculata sub-sp sequipedalis)* and two non-leguminous cover crops (Melon M) and Sweet potato (S) planted in all possible combinations (AM, AS, MS and AMS) at three planting densities (20,000, 30,000 and 40,000 stands ha^{-1}) used primarily for weed control on soil conservation and maize production were evaluated in this study. Generally, the cultivation of CCM to manage weeds in maize decreased Ca (6.93%), K (24.76%), Na (9.5%), pH (H2O) (8.9%), pH (KCl) (5.6%), exchangeable acidity (15.8%), CEC (15%), silt and clay (4.5%), silt (15%) and available P (56.2%). However, fine sand (1.3%), Mg (1.5%), OC (22.6%), N (24.9%) and clay (30.5%) were increased relatively to the 2008 soil status. AMS treated plots had the highest magnitude of increase in OC. The order of OC improvement was AMS > AM >MS >AS. While increase in TN was AMS > AM >AS >MS. Reduction in available P was highest in AM treated plots (90.4%), followed by AS and then MS, while AMS caused the least reduction in P. Fine sand was slightly increased in most treatments. The highest improvements in chemical and physical properties of soil were observed at 20,000 – 30,000 stands ha^{-1} of AMS and AM respectively and thus recommended for maize farmers.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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