Vol. 13(2), pp. 23-35, April-June, 2022
DOI: 10.5897/JSSEM2020.0818
Article Number: 25427FC69006
ISSN: 2141-2391

http://www.academicjournals.org/JSSEM

ACADEMIC JOURNALS
expand your knowledge

Journal of Soil Science and Environmental Management

Full Length Research Paper

Nutrient uptake and use efficiencies of strip intercropped cassava, maize and pepper as affected by fertilizer type and age of oil palm fields in an oil palm-based intercropping system

Obi E. A.[1], Agele S. O.[2*], Aiyelari O. P. [2], Adejoro S. A.[2] and Agbona A. I.[3]

[1]Division of Agronomy (Plantation Management), Nigerian Institute for Oil Palm Research (NIFOR), Benin City, Nigeria.
[2]Department of Crop, Soil and Pest Management, Federal University of Technology, Akure, Ondo State, Nigeria.
[3]Department of Agricultural Technology, Federal Polytechnic, Ile Oluji, Ondo State, Nigeria.

Received 5 April 2020; Accepted 18 May 2020

Field trials were conducted to examine the responses of Cassava, Maize and Pepper to fertilizers in the alleys of 3, 4 and 6 years oil palm fields. Fertilizers: NPK (1.44 kg/plot), Ferti Plus (9.68 kg/plot) and poultry manure (6.17 kg/plot) were applied two weeks after planting. Results showed that fertilizers significantly influenced N uptake and some indicators of N use efficiencies measured. NPK enhanced uptake and apparent recovery of N and Ferti Plus (organo-mineral fertilizer) and poultry manure promoted agronomic and physiological efficiencies of N use. Uptake and yields of N were higher for sole crops compared with intercrops across the fertilizers. Cassava and maize had enhanced N removed at harvest, Internal utilization efficiency (IE) and apparent recovery efficiency (RE), and pepper had higher IE, Apparent Recovery Efficiency (RE), Agronomic and Physiological Efficiency (PE) of N use. Age of oil palm fields and fertilizers influenced nutrient uptake and use efficiencies of the alley intercrop species. Nitrogen uptake and use efficiencies were highest for 4 and 6 years compared with the 3 years old fields across the intercrop species. NPK and Ferti Plus had higher efficiencies of uptake and use of N compared with poultry manure across the ages of oil palm fields. It is concluded that, alley intercrop species differed in uptake and use efficiencies of N. The alleys of oil palm of 1 to 6 years supported the performance of intercropped arable species and fertilizers enhanced soil nutrients and crop yields.

Key words: Alley, oil palm, arable, resources, fertility, uptake, use, efficiency, yield.

INTRODUCTION

Intercropping, an important feature of the farming systems of the tropics, is defined as the simultaneous growing of two or more species in the same field for a significant period of their growth. Intercropping systems offer crucial ecosystem service that supports food supplies and other livelihood activities (Willey, 1995; Vanlanwe et al., 2011). Such practices provide sustainable and stable yields, diversity of flora and fauna

*Corresponding author. E-mail: soagele@futa.ec, du.ng:ohiagele@yahoo.com.

and lower risks of crop failure, as well as implement, sustain and enhance environmental quality, ecosystem services and livelihoods along with sustainable landscapes (Ajayi et al., 2016; Agele et al., 2018a). Intercropping practices are reported to optimize ecological processes including the cycling of nutrients, maintains carbon stocks and its sequestration, conservation of soil water and modification of microclimate and reduce soil degradation (Vanlanwe et al., 2011; Agele et al., 2018a).

Agroforestry involves growing trees in mixtures and arable/food crops and fruit tree species simultaneously on a farm (growing arable crops and fruit tree species in mixtures). Alley cropping is an agroforestry technique in which trees are planted in hedgerows, and annuals (arable or fodder) crops are planted in the "alley ways" between the hedge row plants. Alley cropping involves growing short duration trees and shrubs that are compatible with arable or fodder cropping (in alleys (interrow spaces). Alley cropping involves growing short duration trees and shrubs that are compatible with arable or fodder crops. The trees provide other benefits such as reducing erosion, maintaining soil fertility and providing additional income to farmers and landowners, and offers opportunities for farmers in terms of crop diversity and food security in the early years of tree establishment (Vanlauwe et al., 2011). The advantages of alley cropping are attributable to increases in long-term sustainability by improving soil quality, increased economic diversity, carbon sequestration, farm yield, resource use efficiencies, and environmental resilience (Willey, 1995; Bedoussac and Justes; 2010; Malay et al., 2014).

Variable availability of growth resources with ages of trees following its establishment exist; thus the variability in the capture and use efficiencies by hedge row crops and alley crops (component species). Research on intercropping has shown that fruit trees can be intercropped successfully with arable crops during the early stages (1 to 5 years) of establishment. Information is inadequate with respect to the performance of alley crops in the fruit tree-based agroforestry systems of the savanna agroecologies of Nigeria. There is therefore merit in research for enhanced understanding of performance of arable species such as cassava, maize and pepper as alley crops in the early years of oil palm and as alternative cash crop for fruit tree farmers and crop diversification during the early stages (establishment) of their growth. Optimum species combination of arable species in the alleys of oil palm would optimize the benefits of competitive interactions based on resource availability and use by the intercrops and oil palm. Rapid depletion of soil nutrients and further degradation of soil quality in sub-Saharan Africa is a challenge to agriculture, where annual N depletion rate is about 26 kg $year^{-1}$ (Stoorvogel et al., 1993; Moisier et al., 2004). In agriculture worldwide, efforts to increase crop yields and quality to meet rising demand for food from growing population, has been based on the use (application) of fertilizers both from inorganic and organic origins (FAO, 2011). Paul and Mannan (2007) and Agele et al. (2011) opined that sustainable soil fertility management and sustainable agriculture can be achieved with the use of both mineral (inorganic) and organic fertilizers. Fertilizer application has been reported to improve nutrient use efficiency and chemical and nutritional quality of crops (Moisier et al., 2004; Agele et al., 2011). However, in the tropics, high costs and accessibility of fertilizer constitute huge constraints to the success of fertilizer use (FAO, 2011). High N uptake and utilization efficiency by crops without deleterious effect on yield and ecosystem are required (Scholberg et al., 2000; Agele et al., 2008). Nitrogen use efficiency (NUE) for crop production is less than 40% worldwide (Stoorvogel et al. 1993; Raun and Johnson, 1999; Agele et al., 2018b; Tsadik, 2019). Research is required to improve crop NUE and yield and develop sustainable fertilizer usage in response to increasing economic and environmental concerns. Lopez-Bellido and Lopez-Bellido (2001) and Agele et al. (2008) have shown that nitrogen use efficiency is affected by cropping systems, fertilizer types and application rate. The efficiencies of nitrogen uptake and use for yield production and hence nitrogen harvest index (NHI) is strongly affected by nutrient availability from fertilizer sources. Availability of soil N, the efficiency of its uptake and use in biomass and fruit production are also affected by crop types, soil and climatological characteristics of a region (McCall and Willumsen, 1998; Agele et al. 2008, 2011). Yamoah et al. (1998), Nevens et al. (2004) and Agele et al. (2008; 2011) concluded that NUE efficiency affected by soil nutrient enrichment from fertilizer sources. Rather et al. (1999) and Agele et al. (2008; 2011) opined that crop yields may increase under fertilizer treatments possibly due to improved efficiency of nutrient uptake and use. Uptake, use and partitioning of N between vegetative and reproductive components are commonly used in addition to other criteria in the selection for yield in crops (Agele et al., 2008) and to create cultivars adapted to low input management systems. Although these attributes vary in diverse ecologies, there are however, information is inadequate on uptake and use efficiencies of soil N in crop species common to the cropping systems of the humid tropics (Akintoye et al., 1999; Agele et al., 2008).

The objectives of to examine the responses of Cassava, Maize and Pepper to application of NPK, Ferti Plus (an organomineral fertilizer) and poultry manure when sown as strip intercrops in the alleys of 3, 4 and 6 years old oil palm. The aim is to improving understanding of effects of fertilizer application for enhancement of nutrient (fertility) status, growth and yields of alley intercrops, and fertilizer types influence on N uptake and use efficiencies from applied fertilizers for biomass and yield production in an oil palm-based intercropping system of the rainforest zone of Nigeria.

MATERIALS AND METHODS

Studies were conducted to determine the effects of fertilizer (NPK, Poultry manure and organic pelletized organic fertilizer) and age (3, 4 and 6 years) of oil palm on nutrient uptake and use efficiencies of strip intercropped cassava, maize and pepper in an oil palm-based intercropping system. This study was conducted at Nigerian Institute for Oil Palm Research (NIFOR) Experimental Fields. Cassava, maize and pepper were strip-intercropped in the alleys of of oil palm of different ages. The fertilizers (NPK, Ferti plus and poultry manure) were respectively applied at the rate of 67.5, 168.75 and 337.5 g/plant) as determined by the soil test. The indices of N uptake and agronomic and physiological efficiencies of N use were calculated using the procedures described in the literature (Gungunla, 1999; Fageria and Baligar, 2003; Dobermann, 2007; Quanbao et al., 2007).

Nutrient uptake refers to the ability of crop to extract or absorb nutrients from the soil. The uptake of nitrogen was calculated as the product of the measured N concentrations in shoot biomass and reproductive structures (fruit/seed/tuber) the weight of the biomass (shoot and reproductive structures) (Gungunla, 1999, Fageria and Baligar, 2003).

N Uptake = Yield of grain or straw (kg ha^{-1}) x N concentration of grain or straw (%)

N uptake efficiency was computed as:

$$\text{Uptake efficiency} = \frac{\text{total above} - \text{ground nutrient in the plant at maturity}}{\text{Nutrient Supplied (NS)}}$$

The proportion of total plant N partitioned to the shoot is called the N harvest index (NHI). It is also defined as the percentage of grain N uptake to total plant N uptake (Fageria et al., 2003).

$$\text{N harvest index (NHI)} = \frac{Shoot\ N\ uptake}{total\ plant\ N\ uptake}$$

Nutrient Use Efficiency (NUE): This is a term used to indicate the ratio between the amount of fertilizer N removed from the field by the crop and the amount of fertilizer applied. NUE is expressed in several ways as the efficiency of conversion of nutrient taken up by the plant into crop biomass. This ratio describes the efficiency of N fertilizer utilization in crop production.

$$\text{NUE} = \frac{(\text{N crop uptake fertilised} - \text{N crop uptake unfertilised})}{\text{N fertilizer (mineral N)}} \times 100$$

The conversion of efficiency (CEN) of nutrient taken up from the soil solution is defined as:

$$\text{CEN} = \frac{\text{total above ground biomass}}{\text{Total nutrient uptake}}$$

Total above ground biomass is the sum of root and shoot biomass expressed on a dry weight basis.

Agronomic Efficiency (AE) is calculated as the unit of yield increase per unit nutrient applied. It reflects the direction of production impact of applied fertilizer and also relates to economic return. The calculation of AE requires knowledge of yield without nutrient input, so is only known when research plots with zero nutrient is been implemented on the farm (Vanlauwe et al., 2011). AE is expressed in several ways as reported in literature as the efficiency of conversion of nutrient taken up by the plant into crop biomass

$$\text{AE} = \frac{\text{Y} - \text{Yo}}{\text{F}}$$

where AE is agronomic efficiency, Yn is crop yield (kg/ha) from plots that received fertilizer while Yo is yield from plot without fertilizer, and Fn is the amount of nutrient applied (kg/ha).

Physiological Efficiency of N use (PE): is defined as the yield increase in relation to the increase in crop uptake of the nutrient in above ground parts of the plant (Dobermann, 2007). Similar to AE, it needs a plot without application of the nutrient of interest to be implemented, and requires measurement of nutrient concentrations in crop biomass (shoot and reproductive structures).

$$\text{PE} = \frac{(\text{Y} - \text{Yo})}{(\text{U} - \text{Uo})}$$

where PE = physiological efficiency of N use, Y = crop yield with applied nutrient, Yo = crop yield with no applied nutrient, U = plant nutrient uptake of above ground biomass at maturity, Uo = plant uptake with zero fertilizer.

Apparent Recovery Efficiency (ARE): is the ratio of nutrient uptake to nutrient applied, it is also defined as the difference in nutrient uptake in above ground parts of the plant between the fertilizer treated and untreated crop relative to quantity of nutrient applied. Like AE, ARE can be measured when a plot without nutrient has been implemented on the site, but in addition requires measurement of nutrient concentration in the crop.

$$\text{ARE} = \frac{\text{Nn} - \text{No}}{\text{Fn}}$$

where ARE is apparent recovery efficiency, Nn and No (kg/ha) are nutrient uptake by the crop with and without the applied nutrient respectively, Fn (kg/ha) is the amount of nutrient applied.

Nutrient utilization efficiency (NUE) is calculated as the product of physiological and recovery efficiency. It is calculated based on the method described by Dobermann (2007).

$$\text{NUE} = \text{PE} * \text{ARE}$$

Internal Utilization Efficiency (IE) is defined as the yield in relation to total nutrient uptake. It varies with genotype, environment and management. IE is an indication of the efficiency of internal nutrient conversion, which may be affected by other stresses (deficiencies of other nutrients, drought stress, heat stress, mineral toxicities, pest etc.) (Dobermann, 2007).

$$\text{IE} = \frac{\text{Y}}{\text{U}}$$

where Y is the yield of harvested portion of crop with nutrient applied and U is the total nutrient uptake in above ground crop biomass with nutrient applied

The total factor productivity (TFP) relates an index of output to a composite index of all inputs while Partial Factor Productivity measure relates output to a single input. Partial Factor Productivity (PFP) is a simple production efficiency expression, calculated in units of crop yield per unit of nutrient applied (Dobbermann, 2007).

$$\text{PFP} = \frac{\text{Y}}{\text{F}}$$

Table 1. Effects of fertilizers and intercrops on N content and uptake, crop yields and nitrogen harvest index (NHI).

Fertilizer and Intercrop		N contents	Biomass	PuN	PuO	PuN (sole)	Intercrop mixture yield (+N)	Mixture yield (unfertilized)	Sole crop yield (N)	Sole crop yield (unfertilized)	NHI Mixture	NHI sole crop
Cassava	NPK	1.81	1212	1775.61	1324.35	1844.3	37.8	31.2	42	35.7	0.047884	0.058013
Maize		1.68	125	164.64	113.68	178.1	11.3	10.4	14.2	11.4	0.148673	0.161538
Pepper		2.03	129	170.52	126.84	205.0	12.3	11.2	15.3	12.3	0.165041	0.18125
Cassava	Poultry manure	1.49	1108	1183.06	897.22	1247.2	33.7	27.3	37.6	35.7	0.044214	0.054579
Maize		1.38	109	111.78	87.48	187.0	10.4	8.3	13.4	11.4	0.132692	0.166265
Pepper		1.54	97	113.96	88.06	173.4	11.7	11.2	14.6	12.3	0.131624	0.1375
Cassava	Ferti Plus	1.53	1194	1320.39	957.93	1844.4	31.3	26.8	37.4	35.7	0.048882	0.05709
Maize		1.37	118	119.19	87.87	154.5	9.3	7.4	11.7	11.4	0.147312	0.185135
Pepper		1.73	123	134.94	102.96	172.4	10.8	9.3	14.1	12.3	0.160185	0.186022
	LSD	0.37	35.98	20.57	17.73	21.9	2.74	2.47	2.84	2.33	0.005	0.004
Fertilizers (Fz)		*	*	*	*	*	*	*	*	*	*	*
Crop types (Ct)		*	*	*	*	*	*	*	*	*	*	*
Fz*Ct		*	*	*							*	*

where Y is yield of harvested portion of crop with nutrient applied and F is the amount of nutrient applied.

Data analysis

Data collected were analysed following analysis of variance (ANOVA) procedure of SAS (2007 version), and significant treatment means were separated for 5% ($P < 0.05$) probability level.

RESULTS

The fertilizers exerted significant effects on nitrogen uptake for biomass and yield production of cassava, maize and pepper strip intercropped in the alleys of 3, 4 and 6 years oil palm plots. Compare with Ferti Plus and poultry manure, NPK compound enhanced the contents, uptake and yields of N for shoot biomass and yields of both the sole crop and intercrop mixtures of cassava, maize and pepper (Table 1). The uptake and yields of N were higher for the respective sole crops of cassava, maize and pepper compared with the strip intercrops. While N content was highest for fruits of pepper, highest N uptake and N yields were found for cassava leaves and tubers. Poultry manure had varied effects on nitrogen contents, N uptake and N yields of the intercrops, biomass and tuber yields were heaviest for cassava therefore, its N uptake and N yields were higher compared with maize and pepper under application of poultry manure. The effects of ferti plus organo mineral fertilizer on N uptake and N yields of the intercrops was similar to that of poultry manure (Table 1). The interaction of intercrop and fertilizer types were significant for most of the indicators of nutrient uptake measured (Table 1).

Across the ages of oil palm fields (3, 4 and 6 years), the fertilizers (NPK, fertiplus and poultry manure) enhanced the nutrient uptake of sole and intercropped alley crops of cassava, maize and pepper. There were significant differences for N uptake among the ages of oil palm and fertilizer types applied. NPK, Ferti plus and Poultry manure enhanced the nutrient uptake for cassava (biomass) planted in the alleys of 3, 4 and 6 years old palm. However, NPK produced slight increases in N uptake of cassava under 4 and 6 years old oil palm compared with other fertilizers (NPK, Ferti Plus and poultry manure (Table 2). The fertilizers and age of oil palm affected nutrient uptake in the leaf and seed of maize. NPK and Ferti plus significantly enhanced leaf and seed nutrient uptake of maize compared to poultry manure across the ages of oil palm. The values of

Table 2. Effects of fertilizers and intercrops on agronomic an physiological efficiencies of N use.

		Agronomic efficiency of fertilizers	Physiological efficiency of fertilizers	N recovery efficiency	Apparent recovery of N	Utilization efficiency of N	Internal utilization efficiency	Partial factor productivity	N conversion efficiency	N removed at harvest	Relative interaction intensity	Competitive ability for nutrients
Cassava		247.61905	0.0146257	1.504200	15	0.2193857	0.0212885	0.12600	0.5524862	1771.1955	0.809406	0.2907
Maize	NPK	276.10619	0.0176609	0.169866	1.7	0.0300235	0.0686346	0.03767	0.5952381	164.26107	0.784000	0.2626
Pepper		273.17073	0.0251832	0.145600	1.4	0.0352564	0.0721323	0.04100	0.4926108	170.0972	0.651162	0.2635
Cassava		4050.4451	0.0223901	1.084666	11	0.2462916	0.0284855	0.00674	0.6711409	1182.8806	0.716606	0.3032
Maize	Poultry manure	3990.3846	0.0864198	0.004860	5	0.4320988	0.0930399	0.00208	0.7246377	111.7625	0.743119	0.2561
Pepper		4786.3248	0.019305	0.005180	6	0.1158301	0.1026676	0.00234	0.6493506	113.9423	0.762886	0.2644
Cassava		381.81818	0.0124152	0.906150	9	0.1117365	0.0237051	0.07825	0.6535948	1017.110	0.722780	0.2745
Maize	Ferti Plus	389.74359	0.0606641	0.078300	8	0.4853129	0.0780267	0.02325	0.7299270	118.9703	0.737288	0.2475
Pepper		348.93617	0.0469043	0.079950	9	0.4221388	0.0800356	0.02700	0.5780347	134.6826	0.634146	0.2423
LSD (0.05)		1991.04	0.025	0.566	4.36	0.176	0.031	0.041	0.079	62.68	0.057	0.019
Fertilizers (Fz)		*	*	*	*	*	*			*	*	*
Crop types (Ct)		*	*	*	*	*	*			*	*	*
Fz*Ct			*					*	*			*

N uptake was higher under young palms (3 and 5 years old) and least for 6 years old for maize crop. Similarities were found for the effect of fertilizers on leaf and seed nutrient uptake and for 3 and 5 years old oil palm. Ferti plus and NPK enhanced N uptake in the seed of maize sown in the alleys of 3 and 4 years old oil palm compared 6 years old oil palm.

The intercrops and fertilizers (NPK, Poultry manure and Ferti plus) affected the measured indicators of nutrient uptake and use efficiencies across the ages of oil palm fields (Table 2a). For cassava, ferti plus promoted both efficiencies of N recovery efficiency of applied fertilizers and physiological efficiency of its use. Similar to ferti plus, poultry manure enhanced the utilization efficiencies of nutrients from the applied fertilizers. NPK enhanced both recovery and utilization efficiencies of nutrients, partial factor productivity, N removed at crop harvest and the competitive ability for uptake and use of nutrients from the applied fertilizers (Table 3a). In maize, NPK enhanced recovery efficiency from applied fertilizers, partial factor productivity, N removed at harvest and competitive ability for nutrients (Table 2a). Ferti plus enhanced physiological, utilization and conversion efficiencies of nutrients while poultry manure improved physiological and utilization efficiencies of nutrients. In pepper, ferti plus and poultry manure enhanced the utilization efficiency of nutrients while NPK significantly enhanced N removed at harvest. The fertilizers affected almost all variables measured as indicators of agronomic and physiological efficiencies of nutrient use (Table 2a).

The alley intercrop species affected the utilization and recovery efficiencies of N, agronomic and physiological efficiencies of N use and apparent recovery of N from applied fertilizers (Table 3b). The interaction of intercrop and fertilizer type was significant on most of the measured variables of agronomic and physiological efficiencies of nutrient use by the intercrops. Agronomic and internal utilization efficiencies of N were highest for maize and pepper while values for apparent recovery of N, partial factor productivity, N removed at harvest and competitive ability for nutrients were highest for cassava. Nitrogen harvest index (NHI) was lowest for cassava under sole and intercrop compared with maize and pepper (Table 2). Poultry manure and ferti plus (organo mineral fertilizer) enhanced agronomic efficiency, apparent recovery of nutrients from above ground biomass, internal utilization efficiency as well as N conversion efficiency while NPK enhanced partial factor productivity and NHI for both sole and intercrop mixtures.

The effects of fertilizers varied on agronomic (AE) and physiological (PE) efficiencies of N use by both sole and intercrops of cassava, maize and pepper sown into the alleys of 3, 4 and 6 years old oil palm plots (Table 2c). NPK fertilizer promoted these parameters compared with ferti plus, poultry manure and the non-manure plots. The intercrop species (cassava, maize and pepper) also had

Table 3a. Effects of intercrop species on N uptake and utilization efficiency indicators.

Species	N contents	PuN	PuN (sole)	N Yield (mixture)	N Yield (sole crop)	Agronom ic Eff.	Apparent recovery	Internal Utilization Effi	Partial Factor productivity	N conversion Eff	NHI (mixture)	NHI (sole)	N removed @ harvest	Competitive ability
Cassava	1.637	691.42	811.37	21.214	24.93	2000.84	7.014	0.058	0.042	0.62	0.1	0.12	691	0.27
Maize	1.576	454.79	569.95	17.142	20.63	2021.14	6.014	0.067	0.02	0.65	0.11	0.13	455	0.27
Pepper	1.581	450.54	569.14	17.071	20.59	2031.54	7.057	0.068	0.025	0.64	0.12	0.14	451	0.26
LSD	0.1469	6.9033	9.3745	9.434	1.2295	1.2608	3.1552	0.6133	0.0576	0.0755	0.0944	0.002	57.373	0.0023

Table 3b. Effects of fertilizer types on N uptake and utilization efficiency indicators.

Fertilizers	N contents	PuN mixture	PuN (sole)	Yield (mixture)	Yield (sole)	Agron efficiency	Apparent recovery efficiency	Internal utilization efficiency	partial Factor productivity	N conversion Eff	NHI (mixture)	NHI (sole)	N removed@ harvest	Competitive ability
NPK	1.84	703.59	742.5	20.466	23.83	265.63	6.033	0.054	0.068	0.55	0.12	0.13	702	0.75
Poultry	1.47	469.65	535.893	18.656	21.87	427.72	7.333	0.074	0.013	0.68	0.1	0.12	470	0.74
Fert+	1.54	524.84	723.763	17.133	21.07	373.49	8.667	0.062	0.042	0.65	0.12	0.14	524	0.7
LSD	0.09163	57.94006	51.170	0.44828	0.4870	28.8997	0.32197	0.00513	0.01593	0.03341	0.00438	0.0033	57.53	0.00181

higher NHI under NPK fertilizer treatment. Sole crops had enhanced nitrogen harvest index (NHI) compared with intercrops. Nitrogen harvest index was significant by poultry manure compared to NPK and un-manure control for the intercrops. Sole crops of the respective intercrop species significantly influenced agronomy efficiency (AE), utilization efficiency (UE), internal efficiency (IE) and partial factor productivity (PFP) while the intercrop combinations had significantly improved AE, RE, UE, N-removed at harvest. The intercrop species (cassava, maize and pepper) for which NPK was applied had significantly higher AE, RE, UE, N-removed at harvest and PFP. Across the intercrops, NPK fertilizer enhanced the values of these variables compared to poultry manure and the un-manure plants.

The summary of N uptake, N yields, apparent recovery in above ground biomass and indices of agronomic and physiological efficiencies of N use is presnetd in Table 4. In general, the fertilizers following their application to the strip intercrops in the alleys of 3, 4 and 6 years old palm influenced most of the indicators of N use efficiencies measured. Agronomy Efficiency (AE) differed significantly. Apparent Recovery Efficiency (RE), Apparent recovery Efficiency by difference (RE%), Physiological Efficiency(PE), Utilization Efficiency(UE), Internal utilization Efficiency(IE) and partial factor productivity (PFP) were not significantly different among the intercrops under the fertilizers. Fertilizer treatments enhanced most of measured variables of nutrient use efficiencies compared to unfertilized plots (control) (Table 4). The ages of oil palm significantly affected most of the measured variables among the intercrops except the N removed at harvest. However, apparent recovery of N differed among intercrops and ages of oil palm plots. The values of the measured parameters were highest for 4 and 6 years oil palms across the intercrops.

The age of oil palm fields and fertilizers had significant effects on uptake of nitrogen in cassava. The uptake of nitrogen for biomass production in cassava differed among the ages of oil palm and fertilizers applied (Figure 1a). While values were highest under 6 years old under poultry manure, non-significant differences were found among the fertilizers for other ages of oil palm. N uptake for tuber production in cassava was enhanced for the 3 years old field by NPK and 4 years old by poultry manure (Figure 1b). Uptake of nitrogen from applied NPK and ferti plus enhanced biomass production in maize across the ages of oil palm fields. Lowest values of N uptake for biomass production in maize were found for poultry manure among the ages of oil palm

Table 4. Summary of N uptake, N yields, apparent recovery in above ground biomass and indices of agronomic and physiological efficiencies of N use.

Fertilizer and Intercrop	N Uptake	ANR (%)	ANUE (kg/kg)	PNUE (kg/kg)	N yield	NHI	N removed @ harvest	N conversion efficiency
Cassava	513.65	7.02	2011.03	0.0175	21.22	0.10	691.3	0.62
Maize	337.01	8.01	2021.14	0.0211	17.14	0.11	477.7	0.65
Pepper	335.48	7.06	2031.52	0.0233	18.51	0.12	445.6	0.64
LSD	11.51	0.41	31.43	0.001	7.02	0.002	15.31	0.02
Zero	617.5	4.71	248.33	0.012	13.56	0.09	342.4	0.44
NPK	521.62	6.03	365.53	0.019	20.47	0.12	702.5	0.55
Poultry manure	357.59	7.33	427.92	0.027	17.03	0.11	470.3	0.68
Ferti Plus	382.93	8.68	373.49	0.026	18.66	0.12	524.7	0.65
LSD	40.63	0.22	28.34	0.002	0.45	0.003	23.6	0.02
Crop type (CT)	*	*	*	*	*		*	*
Fertilizers FZs	*	*	*	*	*	*	*	*
CTxFZs	*	*	*	*	*		*	*

*ANR (Apparent Recovery of N in above ground biomass); ANUE (Agronomic N use efficiency); PNUE (Physiological N use efficiency).

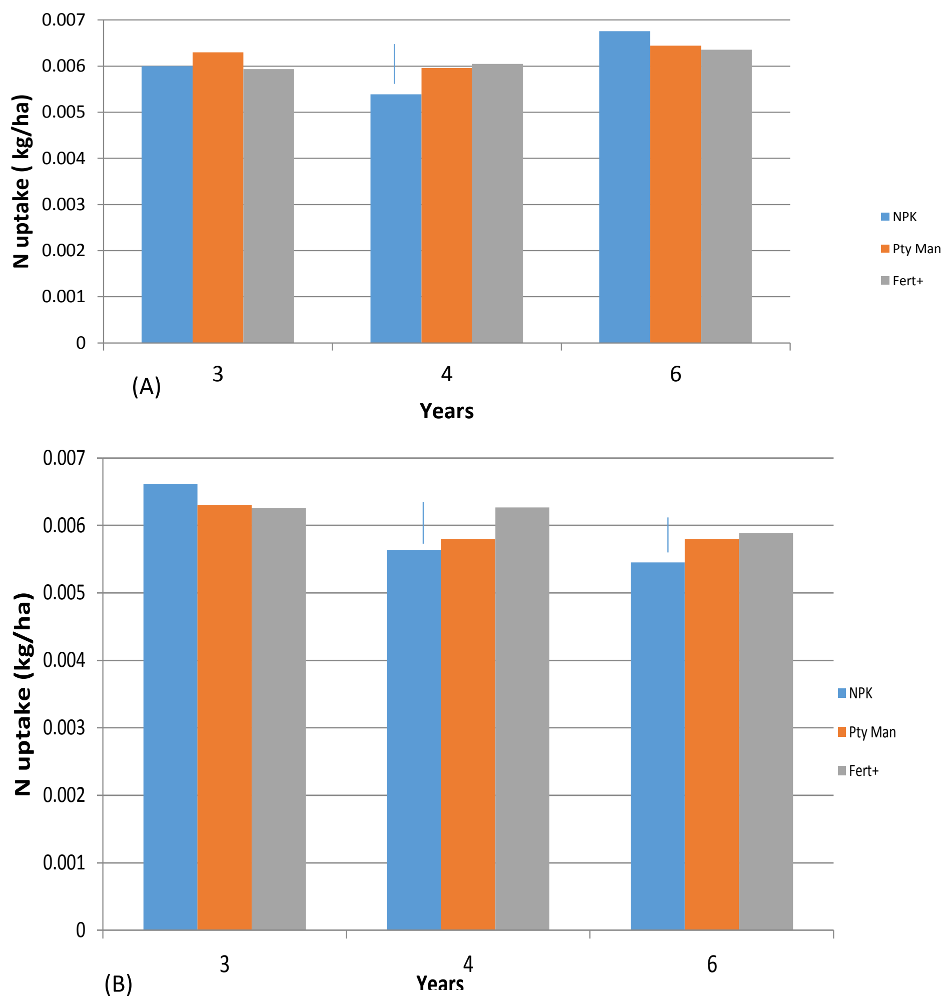
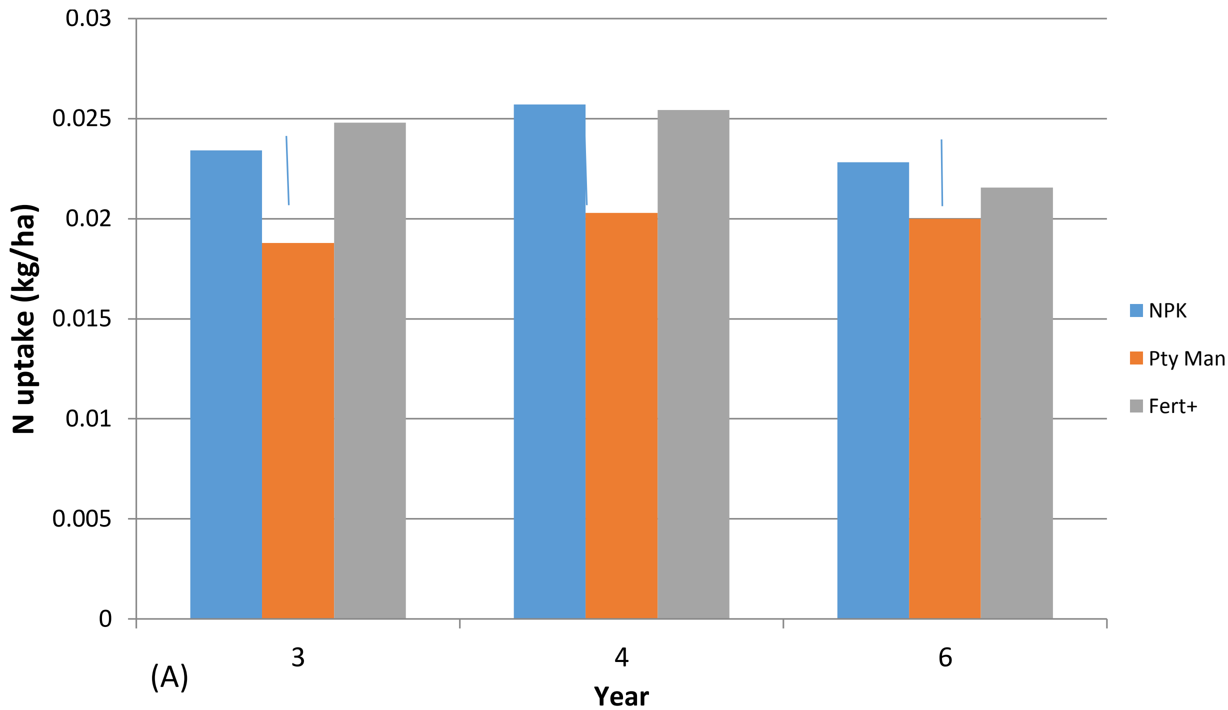


Figure 1. (a) Effect of age of oil palm and fertilizer on cassava N uptake (leaf), (b) effect of age of oil palm and fertilizer on cassava N uptake (tuber).



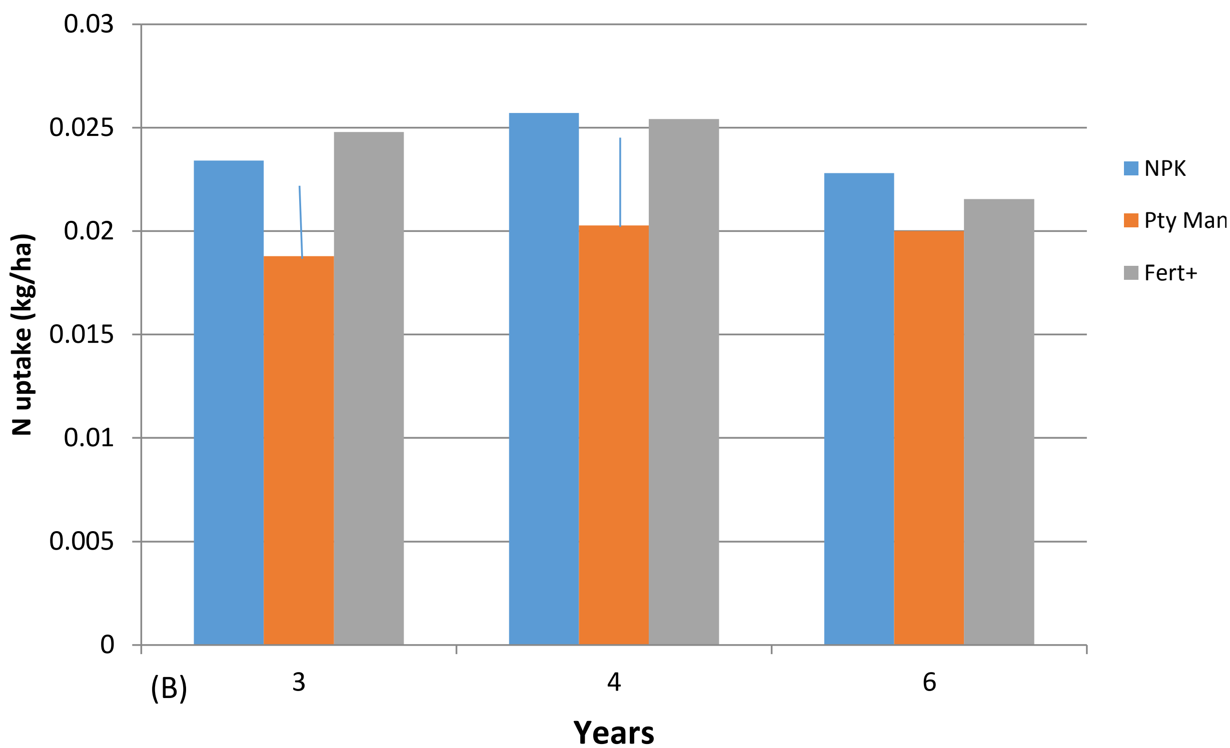


Figure 2. (a) Effect of age of oil palm and fertilizer on maize N uptake (leaf), (b) Effect of age of oil palm and fertilizer on Maize N uptake (seed).

(Figure 2a). Trends of N uptake for seed production in maize follow those of biomass production are mentioned in Figure 2b. NPK and ferti plus enhanced N uptake in maize seeds and lowest values were obtained for poultry manure across the ages of oil palm fields. Fertiplus and NPK enhanced the nutrient uptake in the leaf and fruit of

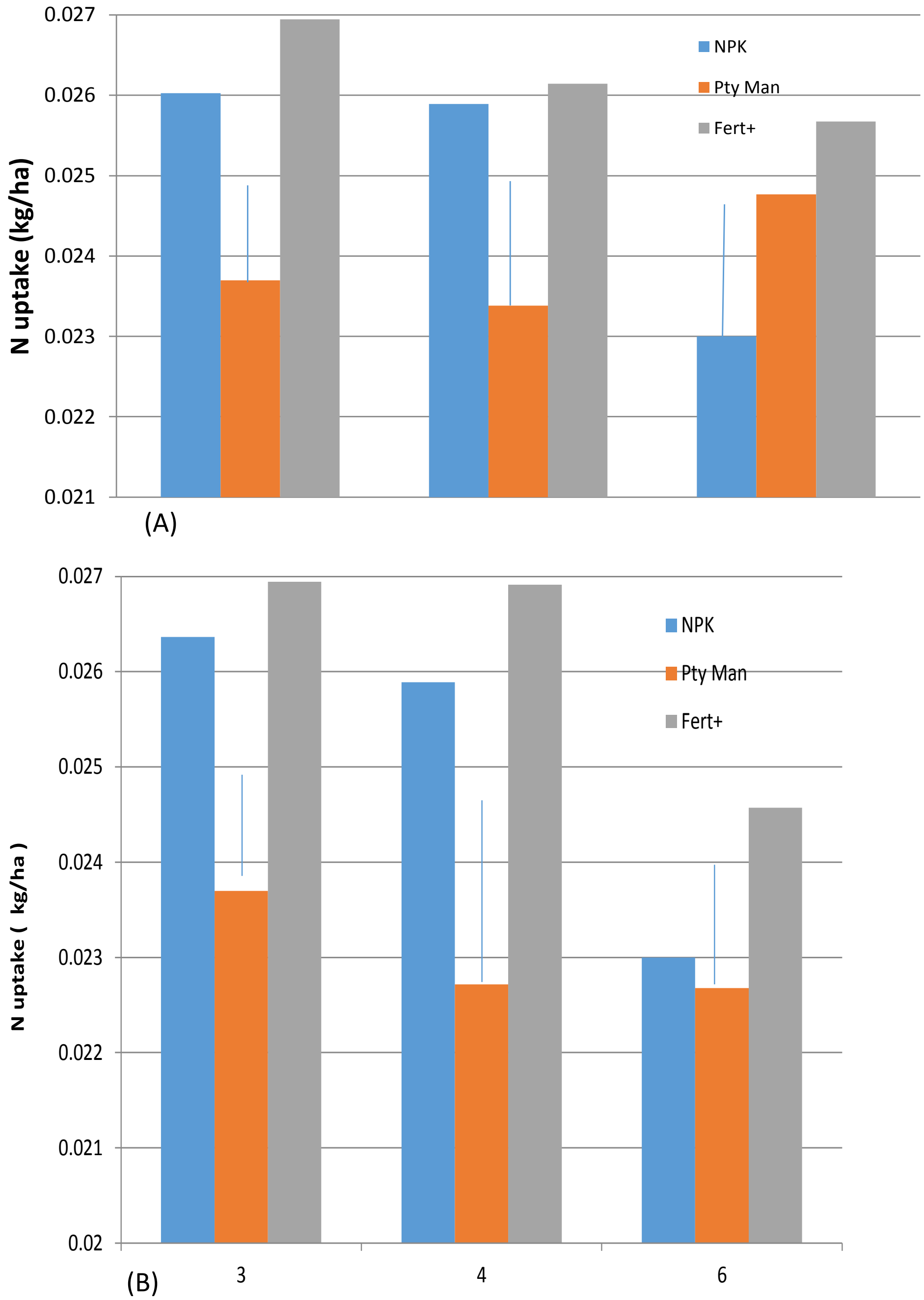


Figure 3a. Effect of age of oil palm and fertilizer on pepper N uptake (leaf), (b) Effect of age of oil palm and fertilizer on pepper N uptake (fruit).

pepper in the alley of 3 years old palm while Poultry manure recorded lowest N uptake. However, NPK recorded the lowest value of N uptake for 6 years old oil palm (Figure 3a and b). Lowest fertilizer efficiency was found for 6 years old oil palm for both leaf and fruits of pepper. Pepper responded more to Ferti plus application in biomass with respect to nutrient uptake for leaf and fruits of pepper (Figure 3a). The fertilizers affected N uptake for fruit production by pepper (Figure 3a). In particular, lowest values were obtained for N uptake for the 6 years old field and for ferti plus, while for other ages of oil palm, highest values were found for NPK and ferti plus and lowest for poultry manure (Figure 3b).

DISCUSSION

The fertilizers: NPK (a compound inorganic fertilizer), Ferti Plus (organo-mineral fertilizer) and poultry manure, exerted significant effects on nitrogen uptake and use efficiencies for biomass and yield production by cassava, maize and pepper strip intercropped in the alleys of 3, 4 and 6 years oil palm plots. Compare with Ferti Plus and poultry manure, NPK influenced most of the measured indicators of N use efficiencies by the sole crop and intercrop mixtures of cassava, maize and pepper in oil palm alley. The un-manured (control) plants had higher N uptake and NHI compared to the fertilizer treated plants. Agele et al. (2008) obtained improved NUE for crops under application of organic and inorganic fertilizers, and Rather et al. (1999) and Agele et al. (2018b) had attributed crop yield increases under fertilizer treatments to improved efficiency of nutrient uptake and use.

The results obtained for nutrient use efficiency indicators in this study showed that the effect of organic (manure) is different from chemical NPK fertilizer. The efficiencies of nitrogen uptake and use for yield production and hence nitrogen harvest indexes (NHI) are strongly affected by nutrient availability from fertilizer sources. Lopez-Bellido and Lopez-Bellido (2001) reported that nitrogen use efficiency is affected by cropping systems, fertilizer types and application rate. McCall and Willumsen (1998), Yamoah et al. (1998), Nevens et al. (2004) and Agele et al. (2011) also affirmed that the availability of soil N, the efficiency of its uptake and use efficiencies for biomass and yield production are affected by fertilizer sources, soil and crop types, and climatological conditions of the production site.

In this study, the alley crop species differed in their NUE responses to the applied fertilizers. Compare with organic fertilizers evaluated, NPK fertilizer had higher N concentration which would have impacted N availability in soil solution and its N uptake and use efficiencies by the sole and intercrop mixtures of the alley crop species. The observed differences in crop responses to inorganic and organic fertilizers can be attributed to differences in nutrient contents, patterns of nutrient release and effects on soil physical, chemical and biological properties (McCall and Willumsen, 1998; Nevens et al., 2004; Agele et al., 2011; Liang et al., 2019). It has been reported that crop species differ in biomass and nutrient uptake, accumulation and partitioning between vegetative and reproductive components (Nevens et al., 2004; Agele et al., 2018b). Differences in uptake, use, accumulation and partitioning of nutrients between vegetative and reproductive components in crop species and varieties are commonly used as criteria for yield selection in crops to develop cultivars adapted to low fertilizer input management systems (Yamoah et al., 1998; Nevens et al., 2004; Agele et al., 2008). Although, organic fertilizers contain other nutrients aside from N which is low, slow release and longer resident time in soil of these nutrients would have extended uptake time, accumulation and utilization for growth and yield of crops (Yamoah et al., 1998; Agele et al., 2011, 2018b). Other advantages of organic fertilizers include improvement in soil physical and biological properties with resultant improvement in growth and yield of crops (Cassman et al., 2002; Liang et al., 2019).

Higher N uptake in addition to NHI by the alley crops was obtained under control treatment (plots for which fertilizers were not applied) compared to plants under fertilizer treatment. Nutrient uptake refers to the ability of crop to extract or absorb nutrients from the soil. N uptake was calculated as the product of the measured N concentrations in shoot biomass and reproductive structures (fruit/seed/tuber) by the weight of the biomass (shoot and reproductive structures) (Gungula, 1999; Fageria and Baligar, 2003). Although, lower biomass (shoot and reproductive structures) weights was obtained for control, N concentration relative to biomass weight was high thus the relatively high N uptake for the control treatment. Other studies had reported high N uptake for crops under control (plots for which fertilizers were not applied) (Agele et al., 2008, 2018b). However, fertilizer application enhanced soil nutrient status, uptake and accumulation of N in the leaf, fruit, tuber and grain of alley crop species.

NPK fertilizer enhanced N-removed at harvest and apparent recovery while poultry manure had enhanced apparent recovery efficiency by difference (RE%), fertilizer use efficiency (FAE) and internal utilization efficiency (IE). Poultry manure treatment significantly influence RE%, PE and IE while N-removed at harvest was significantly higher in the un-manure plants (control). The organo-mineral fertilizer, ferti plus enhanced Apparent Recovery Efficiency by difference (RE%) and Partial Factor Productive (PFP) and Physiology Efficiency (PE) of N use. Ferti plus and poultry manure treatment had higher partial factor productivity (PFP) by enhancement of most of the indicators of N use efficiency compared to the un-manure (control). In general, the fertilizers enhanced Agronomy Efficiency (AE), Apparent Recovery Efficiency ARE, Physiology Efficiency (PE), Utilization Efficiency (UE), N-removed at harvest and Internal Utilization Efficiency (IE), PFP and N-removed at harvest, and partial factor productivity (PFP). In this study, AE values was less than 1, however it has been reported that AE values may range between 1 and 5 since its magnitude is dependent upon soil, crop, nutrient rate of absorption and losses.

In this study, NPK among other things enhanced N uptake and N removal at harvest while the organic fertilizers promoted other indicators of agronomic and physiological efficiencies of N use. This observation is consistent with the reports of differential responses of NUE indicators by crops from inorganic and organic fertilizers. Differences in nutrient uptake, utilization efficiencies and crop yield enhancement between inorganic and organic fertilizers are widely reported (McCall and Willumsen, 1998; Nevens et al., 2004; Agele et al., 2011; Liang et al., 2019). These observations had been attributed to the effects of fertilizers on soil nutrient contents (enhancement of nutrient availability), nutrient release pattern from fertilizer types (sources: organic and inorganic) and physical and biological properties of the soil.

In this study, the fertilizers (organic and inorganic) influenced agronomic and physiological efficiencies and PFP of the alley crop species evaluated. Most of the measured indicators of agronomic and physiological efficiencies of N use express the general production efficiency of the system, the composite measure relating output to inputs. NUE expresses the general efficiency of conversion of nutrient taken up by the plant for biomass production, and it describes the general efficiency of N fertilizer utilization in crop production. Agronomic Efficiency (AE) is indicated as the unit of yield increase per unit nutrient applied; this index reflects the direction of production impact of applied fertilizer and also relates to economic return (Vanlauwe et al., 2011). On the other hand, physiological Efficiency of N use (PE) expresses the yield increase in relation to increases in crop uptake of nutrient in above ground parts of the plant (Dobermann, 2007). Internal Utilization Efficiency (IE) is defined as the yield in relation to total nutrient uptake relates yield of harvested portion of crop from applied nutrient that is ratio of total nutrient uptake and incremental production of above ground crop biomass from applied nutrient. Apparent Recovery Efficiency (ARE) expresses differences in nutrient uptake in above ground parts of the plant between the fertilizers treated and untreated crop relative to quantity of nutrient applied. Nutrient utilization efficiency (NUE) is calculated as the product of physiological and recovery efficiency. NUE indicators are affected by crop species, environment and management and stresses (deficiencies of other nutrients, drought stress, heat stress, mineral toxicities, pest etc.) (Dobermann, 2007).

The findings are consistent with other reports that fertilizers affect availability of soil nutrients and improve uptake, biomass accumulation and use efficiencies of nutrients by crops (Cassman et al., 2002; Agele et al., 2008). The intercrop species differed in shoot morphological and physiological attributes, and rooting patterns of rooting, biomass and nutrient accumulation and partitioning. These attributes have implications for nutrient uptake, use efficiencies and yield production among the alley crop species. Crop species and fertilizer type affected the allocation of uptake and accumulated nutrients to the vegetative and reproductive structures (Agele et al., 2018b; Tsadik, 2019). The uptake, accumulation and partitioning of N between vegetative and reproductive components differ among crop species and varieties; these are commonly used as criteria for yield selection in crops (Agele et al., 2008). Differences among species and varieties are also used develop cultivars adapted to low fertilizer input management systems. Fertilizers (inorganic and organic) trigger different effects on soil and responses by plants especially uptake from soil, nutrient and biomass accumulation and partitioning efficiencies to vegetative and reproductive structures of plant.

The intercrop species (cassava, maize and pepper) for which NPK was applied had significantly higher AE, RE, UE, N-removed at harvest and PFP. Across the intercrops, NPK fertilizer enhanced the values of these variables compared to poultry manure and the un-manure plants. Literature reports has indicated that differences in soil nutrient status are a major source of variation in uptake and use efficiencies and of crop yields (Cassman et al., 2002; Dobermann, 2007; Agele et al., 2018b). These reports had attributed soil nutrient and crop yield enhancement by fertilizers to improvements in the efficiency of uptake and use of nutrient resources for both sole and intercropping systems. In their study, Agele et al. (2018b) observed that without applications of fertilizers, yield and NHI were small for sole and intercrops of sesame and bambara nut in cashew alleys in the guinea savanna agroecology of Nigeria. Fertilizer application enhances nutrient availability and brings about decreases in competition placed on nutrient resources by intercrop species (crop mixtures) (Agele et al., 2018b).

NPK has high N content which is released rapidly into soil solution and promoted its availability, this must have enhanced its uptake by the plant and utilization for biomass production (improved plant growth) compared with organic fertilizers (poultry manure for example). There were therefore, enhanced AE, RE, UE and N removed at harvest for NPK treated plots compared with others. The study showed that application of poultry manure, ferti plus and NPK fertilizers to alley crops in oil palm soil affected nutrient uptake of sole and intercrop species through improved utilization of such nutrient elements. Alizadeh et al. (2010) and Agele et al. (2018a) attributed high yield performance of sole and intercrop combinations of crop species to improvements in efficiency of nutrient resource utilization. Sole crops of the intercrop species under NPK treatment recorded the highest nutrient contents in their leaves which indicates that physiologically, nutrients uptake may depend of the degree of competition (below ground) for resources (Agele et al., 2018b; Tsadik, 2019).

The fertilizers (NPK, Ferti Plus and poultry manure) affected nutrient uptake and use efficiencies of sole and intercrop plant species under oil palm-based alley cropping system: attributable to enhancement of soil nutrients (the sandy loam soil of experimental site appeared to have low fertility status especially N) while improvement in other soil (chemical, physical and biological) properties would have promoted biomass accumulation and yield production by the alley crop species.

In this study, application of poultry manure and ferti plus organo-mineral fertilizes and NPK enhanced leaf and tuber/seed nutrient contents compared with the control (un-manure) treatments. This is attributable to high nutrient inputs by the fertilizers, differences in nutrient demand by the crops, for example, maize, a surface feeder. It is reported that nutrient availability depends on nutrient concentration in the soil and environment and release pattern in synchrony with the crop needs (Agele et al., 2008; Tsadik, 2019). However, highest N uptake values were obtained for the un-manure. Nitrogen harvest index was higher under ferti plus and poultry manure compared with NPK, this result was in line to the conclusion of Agele et al. (2008, 2011) that the crop yields and nutrient availability were higher in plots for which farmyard manure was applied, and to longer time availability. Manure decomposes slowly and releases their constituent nutrients slowly, may be to meet time dynamics of nutrient demand by growing crops (Giller, 2004; Alizadeh et al., 2010). The highest nitrogen harvest index values for seed and leaf of intercrop species were obtained from the un-manure treated plants. The superiority of these may be attributed to more vigorous nutrient exploitation advantage (Tsadik, 2019).

The results showed that for the intercrop species grown under the 3, 4 and 6 years old oil palm plots the fertilizer treatments enhanced Agronomic efficiency (AE), Recovery efficiency (RE) and utilization efficiency (UE), which is an indication of yield improvement compared to treatments without unmanure (Abbasi et al., 2013; Liang et al., 2019). The 3, 4 and 6 years old oil palm plots intercropped with cassava, maize and pepper plants affected physiological efficiency (PE) and Partial factor productivity (PFP). Physiological efficiency (PE) and Partial factor productivity (PFP) values were not significantly different with application of the fertilizer for the intercrops in the alleys of 3, 4 and 6 years oil palm field.

Oil palm also take up nutrient from the soil for its growth, especially from sandy loam soil of experimental sites, nutrient recycling in palms is slow and little (Edy et al., 2020). However, oil palm provides nutritional elements like phosphorus (Tsubo et al., 2001), and nutrient P is reported to decrease species competition placed on nutrient resources (Vanlauwe et al., 2011).

Conclusion

The fertilizers (organic and inorganic) enhanced nutrient uptake and use efficiencies in the respective leaf, tuber, seed and fruits of cassava, maize and pepper in the alleys of 3, 4 and 6 years old oil palm trees. The indicators of uptake and use efficiencies of N differed among the alley crop species and fertilizer types across the ages of oil palm plants in plantation. While NPK promoted the uptake and apparent recovery of N in above ground biomass, the organic fertilizers enhanced other indicators of agronomic and physiological N use efficiencies; and the efficiencies of uptake and use of N were higher for NPK and ferti plus compared to poultry manure. Uptake and use efficiencies of N were higher for the respective sole crops of cassava, maize and pepper compared with the intercrops across the fertilizers. N content was highest for fruits of pepper while N uptake and yields were highest for cassava tubers and seeds of maize.

Cassava and maize had enhanced agronomic efficiency, N-remove at harvest and internal utilization efficiency (IE) and apparent recovery efficiency (RE) while pepper had higher Agronomy Efficiency (AE), Apparent Recovery Efficiency (RE), Agronomic and Physiological Efficiency (PE) of N use. The values of indicators of N uptake and use efficiencies were highest for 4 and 6 years compared with the 3 years old fields across the intercrop species. Physiological efficiency (PE) and Partial factor productivity (PFP) values were not significantly different among the fertilizers applied for the intercrops.

Therefore, it can be said that the intercrop species exhibited differences in their ability to take up and use N efficiently for biomass and economic yield production under application of inorganic (chemical) and organic fertilizers. For arable crops grown in the alley of oil palm (1 to 6 years old), supplementary input of nutrients especially nitrogen from fertilizers (organic and inorganic) is needed to meet the nutrient requirements of alley crops.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abbasi MKM Tahir MM Rahim N (2013). Effect of N fertilizer source and timing on yield and N use efficiency of rainfed maize (*Zea mays* L.). in Kashmir–Pakistan. Geoderma 195:87-93

Agele S, Nduka B, Aiyelari P (2018a). Agro-Waste Reuse and Effects on Growth and Yields of Sesame and Bambara Nut Alley Crops in a Cashew-Based Intercropping System of the Guinea Savanna Agroecology of Nigeria. Advances in Recycling and Waste Management 3(2):159. DOI: 10.4172/2475-7675.1000159

Agele S, Nduka B, Famuwagun B, Adejoro S (2018b). Uptake and Use Efficiencies of Nutrients by Sesame and Bambara Nut Alley Crops as Influenced by Manuring in a Cashew-Based Intercropping System in the Guinea Savanna Agroecology of Nigeria. Journal of Agricultural Chemistry and Environment 7(4):153-175.

Agele SO, Adeniji IE, Alabi IA, Olabomi A (2008). Responses of Growth, Yeild and N use Efficiency of Selected Tomato Cultivars to Variaitons in the Hydrothermal Regimes of the Cropping Seasons in a Rainforest Zone of Nigeria. Journal of Plant Interactions 2(4):273-285.

Agele SO, Adeyemo AJ, Famuwagun IB (2011). Effects of Agricultural Wastes and Mineral Fertilizer on Soil and Plant Nutrient Status, Growth and Yield of Tomato. Archives of Agronomy and Soil Science 57(1):91-104.

Ajayi AJ, Agele SO, Aiyelari OP (2016). Growth, Yield and Yield Components of Pineapple in a Pineapple-Pepper-Cowpea Intercropping System. International Journal of Horticulture 6(1). doi: 10.5376/ijh.2016.06.0001

Akintoye AH, Kling JG, Lucas EO (1999). Nitrogen Use Efficiency of Single, Double and Synthetic Maize Lines Grown at Four N Levels in Three Ecological Zones of West Africa. Field Crops Research 60(3):189-199.

Alizadeh Y, Koocheki A, NassiriMahallati M (2010). Yield, yield components and potential weed control of intercropping bean (*Phaseolus vulgaris* L.) with sweet basil (*Ocimum basilicum* L.). Iranian Journal of Field Crops Research 7(2):541-553.

Bedoussac L, Justes E (2010). The efficiency of a durum wheat-winter pea intercrop to improve yield and wheat grain protein concentration depends on N availability during early growth. Plant Soil 330(1-2):19-35. http://dx.doi.org/10.1007/s11104-009-0082-2

Cassman KG, Dobermann A, Walters DT (2002). Agro-ecosystems, nitrogen-use efficiency and nitrogen management. AMBIO: A Journal of the Human Environment 31(2):132-140.

Dobermann A (2007). Nutrition use efficiency-measurement and management. In "IFA international workshop on fertilizer Best management practices", Brussels, Belgium pp. 1-28.

Edy N, Yelianti U, Irawan B, Polle A, Pena R (2020). Differences in Root Nitrogen Uptake Between Tropical Lowland Rainforests and Oil Palm Plantations. Frontiers in Plant Science 11:92. DOI: 10.3389/fpls.2020.00092

Fageria NK, Baligar VC (2003). Methodology for Evaluation of Lowland Rice Genotypes for Nitrogen use Efficiency. Journal of Plant Nutrition 26(6):1315-1333.

Food and Agriculture Organization (FAO) (2011). FAO STAT: Production, crops, cassava, 2010 data. www.fao.org

Giller KE (2004). Emerging technologies to increase the efficiency of use of fertilizer nitrogen. In: A.R. Mosier, J. K. Syers and J.R. Freney (eds.) Agriculture and the nitrogen Cycle. Scope 65. Island Press Washington DC pp. 35-51.

Gungula DT (1999). Growth and Nitrogen Use efficiency in maize (*Zea mays* L.) in the South Guinea Savanna of Nigeria. PhD. Thesis, University of Ibadan 188p.

Liang H, Zhang X, Han J, Liao Y, Liu Y, Wen X (2019). Integrated N management improves nitrogen use efficiency and economics in a winter wheat–summer maize multiple-cropping system. Nutrient Cycling in Agroecosystems 115(3):313-329.

Lopez-Bellido RJ, Lopez-Bellido L (2001). Efficiency of nitrogen in wheat under Mediterranean condition: Effect of tillage, crop rotation and N fertilization. Field Crop Research 71(1):31-64.

Malay KM, Mahua B, Hirak B, Animesh P, Rajib D (2014). Evaluation of cereal-legume intercropping systems through productivity and competition ability. Asian Journal of Science and Technology 5(3):233-237.

McCall D, Willumsen J (1998). Effects of Nitrate, Ammonium and Chloride Application on the Yield and Nitrate Content of Soil Grown lettuce. Journal of Horticultural Science and Biotechnology 72(2):698-703.

Moisier AR, Syers JK, Freney JR (2004). Agriculture and the nitrogen cycle: Assessing the impacts of fertilizer use on food production and the environment. The Scientific Committee on Problems of the Environment (SCOPE 65), of the International Council on Science, Island Press, London 296p.

Nevens F, Bommele LM, Reheul D, Verbruggen I, De Cauwer B (2004). Reducing fertiliser N use by application of ley-arable rotations. Grassland Science 9:532-534.

Paul GC, Bokhtiar SM, Rashed MA, Mannan MA (2007). Integrated nutrient management for sustainable sugarcane production in different agro-ecological zones of Bangladesh. Planter 83(977):529-53.

Quanbao Y, Hongcheng Z, Haiyan W, Ying Z, Benfo W, Ke X., Zhongyang H. Qigen D, Ke X (2007). Effects of nitrogen fertilizer on nitrogen use efficiency and yield of rice under different soil conditions. Frontiers of Agriculture in China 1(1):30-36.

Rather K, Schenk MK, Everaarts AP, Vethmu S (1999) Response of yield and quality of cauliflower varieties (*Brassica oleracea*) to nitrogen supply. Journal of Horticultural Science and Biotechnology 74 (5):658-664.

Raun WR, Johnson GV (1999). Improving nitrogen use efficiency for cereal production. Agronomy Journal 91(3):357-363.

Scholberg J, McNeal B, Boote KJ, Jones JW (2000). Nitrogen stress Effects on Growth and Nitrogen Accumulation by Field-Grown Tomato Agronomy Journal 92(1):159-167.

Stoorvogel J, Smaling E, Janssen BH (1993) Calculating soil nutrient balances in Africa at different scales. 1. Supra-national scale. Fertilizer Research 35(3):227-235.

Tsadik T (2019). Nitrogen use efficiency of tef [*Eragrostis tef* (Zucc.) Trotter] as affected by nitrogen fertilizer under chickpea-tef rotation at Tahtay Koraro District, North Ethiopia. Journal of Soil Science and Environmental Management 10(4):58-67.

Tsubo M, Walker S, Mukhala E (2001). Comparisons of radiation use efficiency of mono and intercropping system with different row orientation. Field Crops Research 71(1):17-29.

Vanlauwe B, Kihara J, Chivenge P, Pypers P, Coe R, Six J (2011) Agronomic use varieties of groundnut as influenced by sowing dates. Journal of SAT Agricultural varieties Research on Crops 6 (1)-173-174.

Willey RW (1995). Resource use in intercropping systems. Agric Water Manage.17(1-3):215-231

Yamoah CF, Varvel GE, Waltman WJ, Francis CA (1998). Long-term nitrogen use and nitrogen removal index in continuous crops and rotations. Field Crop Research 57(1):15-27.