Agricultural Journal 2 (1): 112-120, 2007

Nitrogen Recovery and Utilisation Efficiencies for Biomass and Fruit Production in Pepper (*Capsicum annum* L.) As Affected by Fertilizer Management Strategies/Methods in a Humid Zone of Nigeria

S.O. Agele, I. Adeyemi and Adebayo
Department of Crop, Soil and Pest Management, Federal University of Technology, PMB 704, Akure, Nigeria

Abstract: In recent years, there has been increased tendency for intensive vegetable production in the tropics and the success of this effort depends strongly on the high application rates of fertilizers to maximise yields. However, in addition to high costs of mineral fertilizer and other logistic problems, intensive vegetable production is constrained by high rate of soil fertility depletion, a bane of continuous cropping systems. Capsicum species are high-value vegetable crops and are also important for human nutrition due to their high nutritional contents. The response of pepper *Capsicum annum* (var. Tatase) to sources of nutrients (nitrogen) and frequency of application (phase application) was analysed in terms of efficiencies of N recovery (uptake) and utilization for shoot biomass and fruit yield (fruit set efficiency) 2004 and 2005 on the field in Akure, a rainforest zone of Nigeria. The aims were to assess the effects of fertilizer materials management on the efficiencies of N uptake and utilisation for fruit setting and fruit yield in pepper. The effects of fertilizer type and frequency of application were significant ($p<0.05$) on growth and fruit yield of pepper. Single and phase application of the fertilizers strongly influenced soil N status and produced differences in pepper growth and fruit yield characters. Over organic fertilizer and control, NPK and FYM + stubble produced significant increases in the dry weights of root (17, 15%; 17.5, 16%) and shoot (15, 16%; 13, 18%), leaf area (16, 13%; 18, 16%) and fruit fresh weight (42, 54%; 40, 20%), respectively. NPK under single and split application maintained uniformly high level of fruit yields than other treatments. Split application of all fertilizer types enhanced leaf area, root and shoot biomass and fruit yields. Source of N and split application (placement methods) significantly improved N recovery and overall N use efficiency. The improvements in pepper growth and yield characters produced under FYM alone and FYM plus plant debris were accompanied by enhanced efficiencies of N fertilizer recovery (uptake), Nitrogen Harvest Index (NHI) and the utilization of N acquired for shoot biomass and fruit production. Residual N in the soil was high under phase application for fertilizer types (organic and mineral) especially for FYM alone and FYM + stubbles. The differences obtained in residual soil N under the different fertilizers and frequency of application could indicate changing availability of soil N as affected by mineralisation rates of the fertilizers. The status of available soil N enhanced ability of pepper to retrieve soil N. Low residual N and hence superior uptake efficiency were recorded under mineral NPK and organic fertilizer compared with FYM application. High residual N was recorded under phase application, the decreases in soil N in plots on which fertilizer was applied once (single application) could indicate more efficient retrieval of soil N from these plots. Agronomic indices used as measure (parameters for estimation of) N use efficiency were computed. These parameters were strongly influenced by fertilizer management strategy adopted in this study. PE_N (physiological N use efficiency), AE_N (Agronomic Efficiency). Increamental yield that results from N application (Agronomic Efficiency, AE_N) increased under phase application of fertilizer types. Although differences in the estimated RE_N appear small, it has large implications in terms of cost savings from reduced fertilizer use (procurement and application) could be attained.

Key words: Manure, split application, yield, NUE, pepper, tropics

INTRODUCTION

Capsicum species are high-value vegetable crops and are also important for human nutrition due to their high nutritional contents. The fruits are important sources of vitamins A, C and E, are eaten as salad vegetables, powdered to make condiments (paprika) and in the manufacture of hot sauces. Capsicum is a genus of

Corresponding Author: S.O. Agele, Department of Crop, Soil and Pest Management, Federal University of Technology, PMB 704, Akure, Nigeria

considerable importance in the tropics[1]. In Nigeria, Capsicum production is wide-spread about 620000t/year of Capsicum fruits is produced[2]. Availability of nitrogen in the soil influences N uptake and accumulation, biomass production, partitioning and fruit yield in a number of crops[3]. Mineral accumulation and utilization is used in addition to other criteria in the selection for yield in crops. Nitrogen Harvest Index (NHI) is the proportion of total plant N that occurs in grain/fruits. NHI is a valuable trait for selection and is therefore useful in breeding programme to create cultivars adapted to low input management systems[4]. High NHI and hence high N use efficiency diminishes the risks of N losses to the environment from crop residues after crop growth. It is necessary to establish optimal nitrogen in plant tissues from applied fertilizer that will promote maximal growth[5]. Agele *et al.*[6] emphasized the need for studies on the nutrient release characteristics of applied fertilizer materials especially organic resources and how the released nutrients march the requirements of arable crops at each stage of their growth. In addition, information is required on fertilizer management techniques that will increase soil nutrient status and timely availability of nutrients for plant uptake and overall nutrient use efficiencies. N splitting may enhance the synchrony between nutrient release and its availability to meet crop requirement at the different growth stages.

The bane of continuous cropping systems of the tropics is soil fertility depletion. Especially for sub-Saharan Africa, nutrient depletion is a huge problem where annual N depletion rates is about 26 kg/year[7,8] . In recent years, there has been increased tendency for intensive vegetable production in the tropics. The success of intensive vegetable production including peppers (*Capsicum* sp.) depends strongly on the high application rates of fertilizers to maximise yields. Logistic problems such as high costs of purchase and accessibility to fertilizer input constitute huge constraints to the success of intensive vegetable production[9,10]. Worldwide, the interest in the use of organic materials as sources of nutrients (fertilizers) for the production of organically grown vegetables had soared. It is therefore pertinent to increase through management practices, N uptake and utilisation efficiencies in crops, this would reduce quantity of fertilizer requirements without deleterious effects on crop yield. Current average levels of Nutrient Use Efficiencies (NUE) from agricultural fields remain well below those that could be achieved with improved technologies[11]. Raising NUE requires a thorough understanding of the environment and management effects on the N cycles on the field. These strategies include real time N management especially split N application. N splitting a strategy emphasizing managing the dynamics of soil N supply from nutrient release to meet crop N demand or requirement at the different growth stages. To reduce fertilizer N losses and reactive N input into the ecosystems will involve effort to increase direct fertilizer N use by the crop during the year of application and to increase the sequestration of fertilizer N not taken up by the crop as soil organic N from where the N can then serve as slow release form of N for subsequent crops[12,13]. Improvement in NUE in crop production systems has emphasized the need for greater synchrony between crop N demand and the N supply from all sources throughout the growoing season[11] . An approach which recognizes the need to use efficiently both indigenous and applied N - mineral fertilizer, organic inputs and indigenous soil N. Since N losses increase in proportion to the amount of available N present in the soil profile at any given time, plant available N pool should be maintained at the minimum size required to meet the crop N requirements at each stage of growth. Fine tuning N management to increase NUE, optimising timing quantity and availability of applied N had been suggested as the key to achieving high recovery efficiencies, to increase agronomic efficiency and the overall NUE[14]. Placement techniques that could avoid excessive accumulation of mineral N in the soil will bring about reduced N losses and improvement in NUE.

Although, residual N fertilizer serves as only a minor source of N to meet the crop's demand, nevertheless, the cumulative effects of residual N fertilizer should not be ignored when management decisions on long term strategies to increase fertilizer N recovery efficiencies are developed[15]. These decisions include target to increase fertilizer N use by crops during first growing season when N is applied and to decrease N fertilizer loss thereby increasing the potential recovery of residual N fertilizers by subsequent crops. Removal of plant growth limiting factors would increase the demand for N by crops leading to higher use of soil available N and overall higher NUE. Reduction in N losses can also lead to increases in recovered N, also, synchronizing N fertilizer application with crop N demand leads to higher N use efficiencies[13]. Smil[12] estimated that worldwide, 50% of all input N was recovered by the harvested crop and their residues. The residual effect of fertilizer N uptake by subsequent crops should be quantified in terms of the amount of fertilizer N that remains available for the subsequent crops[15,16]. Residual N uptake for subsequent growing seasons is known to increase by residue management as well as the input of other organic farm wastes especially livestock manure[16]. Increases in soil organic matter pool has potential to increase yield and N uptake of latter crop.

Optimising timing, quantity and availability of applied N is the key to achieving high recovery efficiencies, increased agronomic efficiency and the overall NUE[14] . It is important to quantify the amount of fertilizer N that remains and the residual effect of fertilizer N uptake by available for the subsequent crops[15,16]. Split application avoids excessive leaching losses, increases NUE due to decreased chances for N losses through leaching, runoff and gaseous emissions[17]. Need to use efficiently both indigenous and externally applied N from input of organic and inorganic fertilizers has been emphasized[14]. Greater synchrony between crop N demand N rates and application times and N supply from all sources during the growing season would increase overall NUE[13]. To reduce fertilizer N losses and its input into the ecosystems will involve effort to increase direct fertilizer N use by the crop during the year of application and to increase the sequestration of fertilizer N not taken up by the crop as soil organic N from where the N can then serve as slow release form of N for subsequent crops[16].

Advocates of best management practices emphasize among other things minimal rates of fertilizers application just enough to be removed by the crops. The need is growing to minimize adverse environmental impacts on water resources resulting from the application of fertilizers/manure to croplands. It is therefore very necessary to determine the right amount of fertilizers to be applied to agricultural lands to achieve the benefits of removing all plant nutrients from the applied fertilizers and for environmental protection. It is important to quantify the amount of fertilizer N that remains in the soil at the end of the cropping season and the effect of residual fertilizer N uptake by subsequent crops[15,16]. Experiments were conducted to evaluate the regulation and optimisation of plant nutrition through management practices that would contribute to increased yields and hence the enhancement of pepper's tolerance of low input management systems and stability of yield under variable soil fertility conditions.

MATERIALS AND METHODS

The cumulative and residual effects of phase application of manures on pepper N nutrition, fruit set efficiency and yields were studied in a *Capsicum* species (*Capsicum annum*, var. *Tatase* the *Zaria* line) in two consecutive early and late cropping season periods in Akure, humid rainforest belt of Nigeria. Seedlings of the various cultivars of *Capsicum* species which are locally adapted, widely grown and consumed in this region, were raised in the nursery and transplanted three weeks later (at five-leaf stage) into field plots of sizes 10×5 m^2 at a spacing of 90x60 cm on 27th March, 2004 and 11th April, 2005 (early/rainy season crop). Each year, trials consisted of factorial combinations of three phase applications- zero, once and twice) of mineral fertilizer, organic manure (pace setter) and farm yard manure (poultry droppings, cow dung and bedding materials partially decomposed state) and 2 levels of plant residue application (residue removed or retained) in three replications to give a total of 29×3 m plots. Phase application consisted of fertilizer placement at zero, once and twice at planting and 2 5wat. A compound mineral fertilizer (N:P:K) was applied at 60 kgN ha^{-1}, 30 kg P_2O_5 and K_2O ha^{-1}. The plots received 100 kg N ha^{-1}, 30 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1} (IAR and T, 1991) while the 100 kgN ha^{-1} level was given in two equal split applications at 2 and 6 Weeks After Transplanting (WAT). Pace setter (organic fertilizer), poultry manure and crushed and dried organic waste materials (FYM -poultry manure and cow dung added to plant residues/debris (leaves of *Grilicidia septum* and *Chromolaena odorata* and mixtures of annual broad leaf weeds). The treatment combinations were arranged in randomized complete block design with three replications.

All plots were sprayed fortnightly with Dithane M45 (a dithiocarbamate fungicide) to control fungal diseases[2] and Vetox 85 (a cabaryl insecticide) at 28 g 9^{-1} litters of water[18]. Agronomic characters sampled were root and shoot biomass, plant height, 50% flowering date, yield and yield components. Root and shoot biomass were oven-dried at 80°C for 48 h and dry weights were recorded. Leaves were clipped off the stems and leaf area was measured at 50% flowering date with leaf area meter LiCor 2000 (Mayashi Denko, Japan). Twenty plants were sampled from each plot at 8 Weeks After Planting (WAT) for the determination of root and shoot biomass and dry matter yields were obtained from oven-dried plant samples at 80°C for 48 h. Ripened fruits were harvested weekly starting from 9 WAT while the end of fruit harvest was determined by the sharp and increasing decline in the number of harvestable fruits. At 50% flowering date (8 WAT), 20 plants were sampled from treatment replicates for analysis while pooled fruit samples for each replicate were analysed for tissue N and NO_3 concentrations. NO_3-N was determined after KCl extraction and Kjeldahl digestion. Manganese oxide and Devada s alloy were added to the digested samples and filtered, the filtrate was trapped into boric acid and 0.005 H_2SO_4[19]. Soil samples were collected before planting at each season of sowing and immediately after harvest in drill cores from both the topsoil layers (0-20 cm) and the subsoil (25-60 cm) in all plots. Drill cores were taken at three sites within each plot and pooled for every treatment. All soil samples were subsequently analysed for Kjeldahl N. The second trial was established for on 11th April, 2005.

Agronomic indices of Nutrient Use Efficiency (NUE) were computed after Krupnik *et al*[15]. These parameters were: Partial Factor Productivity of fertilizer N (PFP_N) was computed as kg product (YN) kg^{-1} N applied (FN); YN/FN, YN crop yield(kg ha^{-1} kg^{-1} ha^{-1}), Agronomic Efficiency (AE_N) is the ratio of the kg product increase (Yo) kg^{-1} N applied; Yo/FN Yo is crop yield of control plot, Plant N recovery efficiency (RE_N) was obtained as KgN taken up(UN-Uo) kg^{-1} N applied; (UN-Uo)/FN. UN is the plant N uptake (kg ha^{-1}) measured in aboveground biomass at physiological maturity in a plot that received N at the rate of FN and Uo is N uptake measured in above ground biomass in a plot without the addition of N. Physiological Efficiency of applied N (PE_N) is the kg product increase (YN-Yo) per kg fertilizer N taken up; (YN-Yo)/UN-Uo) and PE_N was calculated by dividing the increase obtained in harvested fruit (kg ha^{-1}) relative to the zero N plot by the increase in N recovered (kg ha^{-1}) in the above ground dry matter relative to the zero N plot in the corresponding block.

Similar response pattern were obtained in the two experiments and data collected were averaged over the two years of study for further analysis. Data collected were subjected to Analysis of Variance (ANOVA). Factorial analyses of variance were conducted to estimate the variance components due to fertilizer types (organic and inorganic) and placement methods (phase application) and their interactions on the variables examined[20,21].

RESULTS AND DISCUSSION

The main effects of the factors were significant on growth, nutrient accumulation and yield of pepper. Each fertilizer type at three methods of placement frequencies were examined while combined analyses of variance for fertilizer type by placement frequency showed that the interaction of fertilizer type x placement frequency was significant for most characters examined. In Table 1a, b and c were presented results of chemical analysis of Pace setter organic fertilizer and soil before planting and at crop maturity.

Shoot biomass and fruit yield: The effects of fertilizer type and frequency of application were significant ($p<0.05$) on growth and fruit yield and its components in pepper Table 2. Significant increases in fruit yield were produced by NPK FYM and FYM + stubble over organic fertilizer across the frequencies of application. The effects of fertilizer type and frequency of application were significant ($p<0.05$) on growth and fruit yield of pepper. Single and phase application of the fertilizers strongly influenced soil N status and produced differences in pepper growth and fruit yield characters. There was a marked effect of phase application of fertilizers on root and leaf area development, duration of growth phases (50% flowering date and fruit harvest duration) and on weight and total fruit yield per plant in pepper. Over single application, split application of all fertilizer types increased leaf area, root and shoot biomass and fruit yield of pepper Table 2. Compared with organic fertilizer and control, NPK and FYM + stubble produced significant increases in the dry weights of root (17, 15%; 17.5, 16%) and shoot (15, 16%; 13, 18%), leaf area (16, 13%; 18, 16%) and fruit fresh weight (42, 54%; 40, 20%), respectively. Over single application, split application of all fertilizer types increased leaf area, root and shoot biomass and fruit yield of pepper Table 3. FYM alone and FYM plus plant residues incorporation produced higher fruit yield which constituted about 21% increase over organic fertilizer. NPK under single and split application maintained uniformly high level of fruit yields than other treatments, its application influenced soil N status and hence the significant increases in pepper fruit yield especially under split/phase application. The higher yields of biomass and fruits in pepper were accompanied by enhanced values of Harvest Index (HI) under NPK and FYM application. Under phase application, lower fruit yields were obtained under FYM and FYM plus plant residues and the differences between the frequencies of applicatio did not attain significance. Split application of all fertilizer types enhanced leaf area, root and shoot biomass and fruit yields. The enhanced benefits of organic manure on plant characters and improvements in pepper shoot and fruit yields may be attributed to the establishment of vigorous plants and favourable soil properties and enhanced nutrient recycling.

Nitrogen uptake and use efficiency for biomass and fruit production: Fertilizer type and frequency (split application) of application had pronounced effects on tissue N accumulation. Although, shoot N concentrations differed among the fertilizer types however, similar responses were obtained for all fertilizer types under phase application. However, under mineral fertilizer, pepper accumulated higher N than under organic manures. A generally high concentrations of tissue N and NO_3 was observed under control and fertilized plots (externally applied soil N) in this study. Levels of plant tissue nitrogen concentrations could also indicate

Table 1a: Pacesetter company organic fertilizer nutrient composition

	N	P	K	Ca (% of dry weight)	
Grade A pace setter	1.16	1.48	1.82	3.62	
					Total Kg Nutrients
Grade A pace setter	0.58	0.74	0.91	1.81	4.04
					(Kg nutrient 50 Kg^{-1} bag
NPK 15:15:15 (mineral compound fertilizer)	7.5	7.5	7.5	-	22.50

Pace setter is an commercial organic fertilizer produced from composted organic refuse municipal/urban wastes, Source: G.O. Obigbesan, 1999. Fertilizers: Nigerian farmers's dilemma. Inaugural lecture, University of Ibadan, Ibadan Nigeria, pp: 37

Table 1b: Pre-planting soil chemical properties (mean of two experiments)

pH	N (g kg^{-1})	P (mg kg^{-1})	K	Ca	Mg	Organic matter (g kg^{-1})
			------------------ (cmol kg^{-1} soil) -----------------------			
7.20	0.28	2.57	0.23	1.20	1.10	2.28

Table 1c: Soil chemical properties at crop maturity

Treatment	pH	N (g kg^{-1})	P mg kg^{-1})	K	Ca	Mg	Organic matter (g kg^{-1})
				----------- (cmol kg^{-1} soil) -----------------			
Control	5.56	0.25	2.47	0.21	1.30	0.60	1.17
NPK							
Once	6.37	0.43	6.33	0.22	1.46	0.59	1.12
Twice	6.64	0.57	6.71	0.27	1.42	0.62	1.15
Organic fertilizer							
Once	6.71	0.27.	5.55	0.32	1.50	0.74	1.19
Twice	6.92	0.32	7.13	0.39	1.63	0.83	
FYMOnce	6.90	0.26	5.33	0.40	3.07	0.80	
Twice	7.10	0.46	6.24	0.52	3.61	0.83	1.29
FYM + Plant residues							
Once	7.10	0.48	5.42	0.44	3.25	0.84	1.28
Twice	7.30	0.62	6.51	0.57	3.81	0.92	1.33
LSD (0.05)	1.21	0.06	2.56	0.08	1.06	0.12	0.08

Table 2: Growth and yield characters of capsicum as affected phase fertilizer application

Fertilizer types	Application frequency	Root dry weight (g $plant^{-1}$)	Shoot dry weight (g $plant^{-1}$)	Total biomass (g $plant^{-1}$)	Leaf area $plant^{-1}$	50% flowering date (days)	Fruit harvest duration	Fruit weight (g $plant^{-1}$)	Fruit yield (tha^{-1})
	zero	4.9	20.6	24.5	0.53	61	10	418	2.82
NPK	once	6.1	23.3	29.4	0.83	65	14	579	3.28
	twice	6.8	28.5	35.5	0.91	71	16	735	4.07
Organic	zero	4.5	20.2	24.5	0.54	60	10	426	2.81
fertilizer	once	5.7	22.3	27.9	0.68	64	12	478	3.04
	twice	6.3	25.2	30.3	0.80	69	15	583	3.41
FYM	zero	4.7	20.4	25.5	0.52	59	9	431	2.79
	once	5.4	22.7	28.1	0.72	64	11	533	3.19
	twice	6.4	24.2	30.3	0.81	66	13	678	3.68
FYM+plant	zero	4.7	20.4	25.1	0.53	61	10	432	2.81
residue	once	6.1	24.5	30.6	0.75	66	13	574	3.21
	twice	6.6	26.8	33.4	0.82	69	15	695	3.89
LSD (0.05)									
Manures (M)		0.7	2.9	3.6	0.06	4.2	3.1	87.5	1.04
Frequency (F)		0.5	1.6	2.3	0.04	2.7	2.2	52.4	0.70
M x F		*	*	*	*	*	*	*	*

Pacesetter organic fertilizer, FYM (poultry droppings and cow dung, F (,frequencies of application), * significant at $p<0.05$

increased ability of pepper to take up N from the soil for accumulation in biomass and fruit under the various fertilizer types and frequencies of placement. Nitrogen yield is the product of N concentrations and dry matter yields in both biomass and fruit. Treatments with greater shoot yield had relatively greater shoot N yield Table 3, therefore, increases in shoot N yield (content) at anthesis related more to shoot biomass yield. N yields were considerably higher for mineral fertilizer which indicated that these pepper under these treatments was more effective in taking up N from the soil and allocating it into fruits. Nitrogen harvest index (NHI), N partitioning ratio, is the efficiency of dry matter production in relation to the amounts of absorbed N. NHI was distinctly high under phase application across fertilizer types Table 3. NHI is linked with increasing yielding ability of pepper under a treatment possibly in response to status of soil N. Nitrogen harvest index (NHI), the proportion of total plant N that occurs in grain/fruits, is a valuable trait for selection and is therefore useful in breeding programme to

Table 3: Effect of N application on nitrogen concentrations and yield in capsicum

Fertilizer sources	Application frequency	NO_3 conc. ($mg\ g^{-1}$) Shoot	Fruit	N conc. ($mg\ g^{-1}$) Shoot	Fruit	N yield ($mg\ g^{-1}$) Shoot	Fruit	Total	Harvested N NHI	($kgha^{-1}$)
	zero	0.035	0.0028	0.06	0.04	43.3	16.6	59.9	0.0007	60
NPK	once	0.041	0.0047	0.09	0.06	93.5	34.7	127.2	0.0005	127
	twice	0.059	0.0056	0.12	0.08	135.5	53.0	188.5	0.0004	189
Organic	zero	0.032	0.0027	0.05	0.03	35.0	12.7	47.7	0.0006	48
fertilizer	once	0.035	0.0031	0.06	0.04	57.4	18.6	76.0	0.0005	76
	twice	0.038	0.0036	0.08	0.05	70.2	21.7	91.9	0.0004	92
FYM	zero	0.036	0.0027	0.06	0.03	40.3	12.8	52.1	0.0005	52
	once	0.037	0.0043	0.08	0.05	83.2	26.3	109.5	0.0005	110
	twice	0.053	0.0050	0.10	0.07	107.0	47.5	154.5	0.0005	155
FYM+plant	zero	0.034	0.0027	0.05	0.03	34.0	12.9	46.9	0.0006	47
Residue	once	0.039	0.0045	0.09	0.06	95.4	34.4	129.8	0.0005	130
	twice	0.056	0.0053	0.11	0.08	122.1	55.5	177.6	0.0005	178
LSD (0.05)										
Manures (M)		0.008	0.0009	0.004	0.02	24.5	23.7	62.6	NS	28.8
Frequency (F)		0.006	0.0006	0.003	0.02	17.3	14.4	34.3	NS	15.5
M x F		*	*	*	*	*	*	*	*	

Not significant (ns); * sig. at 0.05; ** sig. at 0.01 probability levels

create cultivars adapted to low input management systems[4,9]. Differences in NHI obtained are presumably due to variations in the ability to take up N from the soil and utilize accumulated N in biomass for fruit production under the different treatments. This result points to the fact that the main cause of high NHI and fruit yield in pepper was in the efficiency of N uptake and utilization under the various treatments. This implies that improvement in shoot biomass and N yield at anthesis resulted in higher fruit yield and fruit N content. These responses can partly explain the role of translocation of assimilates formed prior to anthesis in fruit formation in *Capsicum*. The importance of preanthesis assimilated N is confirmed from the magnitudes of NHI and shoot N content in all treatments, shoot N content could therefore explain variations in treatment effects on NHI This was particularly so for fruit nitrogen content and NHI under phase application in both trials. N content of the fruit is derivable from N assimilation during the vegetative phase up to anthesis and/or N assimilated during fruit growth, these processes are reported to depend on the ability of a species/genotype to take up N from the soil and translocate it to the reproductive structures (fruits) in a number of crops[10,22,23]. Availability of nitrogen in the soil influences N uptake and accumulation, biomass partitioning and fruit yield in crops[3]. Under the environmental conditions of the experimental site, multiple application of fertilizers resulted in higher yields without deleterious accumulation of nutrients in the tissues irrespective of differences. High NHI and hence high N use efficiency may diminish the risks of N losses to the environment from plant residues after crop growth.

The efficiency of N absorption by the plants for the production of dry matter and fruits differed among the treatments Table 4. The efficiencies of N utilization for biomass and fruit production were superior in magnitude under phase application Table 4. While the contribution of externally applied soil N to nitrogen utilization efficiencies was greater under phase application pepper exhibited similar N utilization efficiencies under FYM and FYM plus stubble/straw and mineral fertilizer treatments. The observed above zero biomass and fruit yield performance of pepper under zero-N (control) treatment can be related to the high level of available soil N for plant uptake (initial soil N before planting was 560 kg ha^{-1}). Although shoot biomass had higher concentrations of N than fruits in all treatments, the apparent recovery of externally applied N was slightly higher for all fertilizer types under phase application Table 4. Pepper exhibited lower values of apparent recovery of N from externally applied N in the above ground biomass under mineral NPK and FYM plus plant residues than in other treatments. The efficiency of N uptake from the soil was estimated by determining the amount of residual N in soil immediately after harvest Table 4. Residual N in the soil was high under phase application in all the fertilizers applied especially for FYM alone and FYM + stubbles Table 2. The differences obtained in residual soil N under the different fertilizers and frequency of application could indicate changing availability of soil N as affected by mineralisation/decomposition rates of the fertilizers. The differences in available soil N affected the ability of pepper to retrieve N from the soil. In comparison with organic manure application, lower residual soil N in plots on which NPK was applied indicated more efficient retrieval of soil N from these plots. High residual soil N under FYM alone and FYM + stubbles especially under split application connotes inferior uptake efficiency compared to organic fertilizer. Although, plots on which organic wastes were applied (FYM alone and FYM +

Table 4: The effects of N application on the efficiency of N utilization for biomass and fruit production and other agronomic indices used as measures of N use efficiency

	Applied N ($Kg\ ha^{-1}$)	N utilization efficiency: Kg biomass yield kg^{-1} absorbed	N utilization efficiency: Kg fruit N yield kg^{-1} N absorbed	*Residual N in soil at harvest ($Kg\ ha^{-1}$)	Apparent recovery in above ground biomass
NPK	zero	12.2	7.0	--	--
	once	8.2	4.9	300	67
	twice	6.0	3.9	580	123
Organic	zero	13.7	8.9	--	--
fertilizer	once	8.9	3.4	40	28
	twice	4.9	2.8	160	44
FYM	zero	13.5	8.2	--	--
	once	9.5	4.8	240	65
	twice	6.9	4.4	620	103
FYM+plant	zero	14.1	9.2	--	--
Plant residue	once	8.2	4.4	400	83
	twice	6.2	3.9	680	131
LSD (0.05)					
Manures (M)		3.5	2.4	72	37
Frequency (F)		1.4	1.7	34	23
M x F		*	*	*	*

Not significant (ns); * sig. at 0.05; ** sig. at 0.01 probability levels, *Initial soil N before planting was 560 $kgN\ ha^{-1}$; **PE_N (physiological N use efficiency). ** AE_N (Agronomic efficiency), RE_N (N recovery efficiency), PFP_N (Partial factor productivity), PE_N (physiological N use efficiency)

stubble) had higher residual soil N, however the differences between inorganic and organic manure treatments did not attain significance Table 2. Low residual N and hence superior uptake efficiency were recorded under single application. The pronounced difference between plots on which fertilizer was applied once (single application) and split application could indicate more efficient retrieval of soil N from these plots. Under both single and split application of NPK (a mineral fertilizer), N relese matches the nutrient requirements of pepper more closely than under organic fertilizer. However, the faster rates of N release may subject mineral fertilizer to be more susceptible to leaching losses of nutrients[6]. Agele *et al.* [6] observed that slow nutrient release characteristics of livestock (poultry) manure reduced its susceptibility to leaching losses compared with mineral NPK fertilizer during the establishment of amaranthus under the high rainfall regimes of the humid south of Nigeria.

Agronomic indices used as measure (parameters for estimation of) N use efficiency were computed. These parameters were strongly influenced by fertilizer management strategy adopted in this study. PE_N (physiological N use efficiency), AE_N (agronomic efficiency). Increamental yield that results from N application is Agronomic Efficiency (AE_N), this is a measure of NUE computed as the ratio of yield to the amount of applied N. This ratio is also called Partial Factor Productivity (PFP_N). PFP_N is the aggregate efficiency index that includes contributions to crop yield derived from uptake of indigenous soil N, N fertilizer uptake efficiency and the efficiency with which N acquired by the plant is converted to grain yield. Initial N levels in soil are relatively high (Table 1b), high N uptake suggested adequate levels of N in the soil to meet the nitrogen demands of pepper. Source of N and split application (placement methods) did not yield significant differences in N recovery and overall N use efficiency (Table 5). Although differences in the estimated RE_N appear small, it has large implications in terms of cost savings from reduced fertilizer use (procurement and application) could be achieved. RE_N (N recovery efficiency) increased further when straw (plant residues) was combined with FYM (% increase). Other indices of NUE especially Agronomic Efficiency (AE_N), Partial Factor Productivity (PFP_N) and physiological efficiency of N use improved under phase/split fertilizer application. Increase in RE_N could have occurred due to improvements in root development of manured crop. This could have enhanced N uptake from deeper depth compared to unfertilized crop. Plant residues (straw) are an important sink for N and following incorporation and mineralization, it becomes a source of N for the subsequent crops.

It has been reported that plant available N pool should be maintained at the minimum size required to meet the crop N requirements at each stage of growth[14] . The advantage of N splitting could have emanated from a better management of the dynamics of soil N supply and crop N demand. Phase application of fertilizer could have ensured a regular supply of soil N thus avoiding excessive accumulation of mineral N in the soil especially under NPK application. Fine tuning soil N availability with crop N demand through N splitting strategy brought about increases in NUE in the applied fertilizer materials. Phase application of fertilizer N as practiced in this study resulted in high recovery efficiencies, increases in

Table 5: Other agronomic indices used as measures of N use efficiency

	Applied N	Agronomic efficiency (AE_N)	N recovery efficiency (RE_N)	Physiol. PFP_N*	N use efficiency (PE_N)
NPK	zero	--	--	--	--
	once	33.33	2.23	109.33	0.064
	twice	41.67	4.10	135.67	0.010
Organic	zero	--	--	--	--
fertilizer	once	0.01	12.07	1.21	0.082
	twice	0.30	18.97	1.31	0.016
FYM	zero	--	--	--	--
	once	23.53	3.32	137.65	0.062
	twice	52.35	6.06	216.47	0.081
FYM + plant	zero	--	--	--	--
residue	once	13.18	3.17	145.91	0.043
	twice	43.09	5.36	176.82	0.082
Manures	(M)	17.2	2.4	27.4	0.01
frequency	(F)	8.5	1.3	14.6	0.004
M x F		*	*	*	NS

Not significant (ns); * sig. at 0.05; ** sig. at 0.01 probability levels, PFPN (partial factor productivity of N)

agronomic efficiency and the overall NUE. Since N losses increase in proportion to the amount of available N present in the soil profile at any given time, plant available N pool should be maintained at the minimum size required to meet the crop N requirements at each stage of growth. Split application avoids excessive leaching losses, increases in N Recovery Efficiencies (RE_N) could have been due to decreased chances for N losses. Fertilizer placement techniques (e.g., split application) appeared to have reduced excessive accumulation of mineral N in the soil, this could have resulted in enhanced N accumulation and use for fruit production.

To reduce fertilizer N losses and its input into the ecosystems will involve effort to increase direct fertilizer N use by the crop during the year of application and to increase the sequestration of fertilizer N not taken up by the crop as soil organic N from where the N can then serve as slow release form of N for subsequent crops[16]. In this study, synchronizing N application times with crop demand leads to higher N use efficiencies. Improvements in N Use Efficiencies (NUE) through improved fertilizer management practices may contribute to reduction in the quantity of fertilizer requirements without deleterious effects on crop yield. The value of N recovery and use efficiency and NHI recorded for pepper in this study are important traits and useful and component in pepper's performance and adoption under in low input management systems. N splitting strategy emphasizes the management of the dynamics of soil N supply from nutrient release to meet crop N demand or requirement at the different growth stages[13]. Under split application organic waste materials especially appeared to have increased soil organic matter pool can serve as slow release form of N which potential to increase yield and N uptake of latter crop[12,13].

The key to achieving high recovery efficiencies, to increase agronomic efficiency and the overall NUE has been suggested to include fine tuning N management to increase NUE, optimising timing quantity and availability of applied N[14]. Nevertheless, in this study, phase application of agricultural waste materials did not appear to have remarkably enhanced pepper performance. Organic waste materials slowly release their nutrient contents depending on their C:N ratio. Hence, plots on which livestock manure and plant residue were applied had pronounced soil residual N. Longer time is required for mineralization of N content. Application of agricultural waste materials seemed to have optimized timing, quantity and availability of N, enhanced N recovery efficiencies and increased agronomic efficiency and the overall NUE. Improvement in NUE in this study in addition to a greater synchrony between crop N demand and the N supply from all sources throughout the growing season. Improvements in NUE had been reported based on the an approach which recognizes the need to use efficiently both indigenous and applied N (mineral fertilizer and organic inputs)[11]. Oenema and Pietrzak[13] had suggested that a greater synchrony between crop N demand N rates and application times and N supply from all sources during the growing season would increase overall NUE. The residual effect of fertilizer N uptake by subsequent crops should be quantified in terms of the amount of fertilizer N that remains available for the subsequent crops[15,16]. Residual N uptake for subsequent growing seasons is known to increase by residue management as well as the input of other organic farm wastes especially livestock manure[10]. To reduce fertilizer N losses and its input into the ecosystems will involve effort to increase direct fertilizer N use by the crop during the year of application and to increase the sequestration of fertilizer N not taken up by the crop as soil organic N from where the N can then serve as slow release form of N for subsequent crops. In this study, synchronizing N application times with crop demand leads to higher N use efficiencies. Improvements in N Use Efficiencies (NUE) through improved fertilizer management practices may contribute to reduction in the quantity of fertilizer requirements without deleterious effects on crop yield.

Interaction effects: Although the main factors had independent (constant) effects particularly on N uptake, N concentrations in plant tissues and N utilization efficiencies for fruit production and fruit related characters. Significant interactions of fertilizer type by frequency of application were obtained on most variables examined in this study. Based on these analyses, fertilizer type by frequency of application interactions dominated the variations, therefore, frequency of application effect is the predominant source of variation.

CONCLUSION

In the tropics, in addition to high costs of mineral fertilizer and other logistic problems, intensive vegetable production is constrained by high rate of soil fertility depletion, a bane of continuous cropping systems. The success of intensive vegetable production involving peppers (*Capsicum* sp.) depends strongly on high application rates of fertilizers to maximise yields. Logistic problems such as high costs of purchase and accessibility to fertilizer input constitute huge constraints to the success of intensive vegetable production There is need for improvements in the efficiencies of nutrient uptake and utilisation for fruit production from applied fertilizers. Since N losses increase in proportion to the amount of available N present in the soil profile at any given time, plant available N pool should be maintained at the minimum size required to meet the crop N requirements at each stage of growth. Phase application of fertilizer N as practiced in this study resulted in high recovery efficiencies, increases in agronomic efficiency and the overall NUE. Improvement in NUE under phase application in this study could have arisen from a greater synchrony between crop N demand and the N supply from all sources throughout pepper growth. This conclusion recognizes the need to use efficiently both indigenous and applied N - mineral fertilizer, organic inputs and indigenous soil N. Fertilizer management practices adopted in this study optimised pepper nutrition and is attributable to the improvement in N uptake and utilisation efficiencies. Improvements in N Use Efficiencies (NUE) through improved fertilizer management practices may contribute to reduction in the quantity of fertilizer requirements without deleterious effects on crop yield. The value of N recovery and use efficiency and NHI recorded for pepper in this study are important traits will improve understanding in terms of pepper's adaptation to low input management systems.

REFERENCES

1. Purseglove, J.W., 1988. Tropical Crops. Dicotyledons. Longman. London, pp: 232.
2. IAR and T (Institute of Agricultural Research and Training), 2000. Package Recommendation for Food Crops Production in Western Nigeria, pp: 58.
3. Bertholdsson, N.O. and V. Stoy, 1995. Yields of dry matter and nitrogen in highly diverging genotypes of winter wheat in relation to N uptake and N utilization. Agron. Crop Sci., 175: 285-295.
4. Clark, R.B., 1990. Physiology of cereals for mineral nutrient uptake, use and efficiency In: Crops as enhancers of market use; Bahgar, V.C. and R.S. Duncan, (Eds.); Academic Press, New York. pp: 131-209.
5. Bergareche, C. and E. Simon, 1989. Nitrate and ammonium accumulation in bermuda grass in relation to nitrogen fertilization and season. Plant Soil, 119: 51-57.
6. Agele, S.O., S. Adeosun and D. Oluwadare, 2004. A lysimeter study of nutrient release characteristics, leaching losses and effects on growth response of amaranthus resulting from application of inorganic and organic nitrogen sources. J. Food Agric. Environ. (Finland)., 2: 301-306.
7. Stoorvogel, J., E. Smaling and B.H. Janssen, 1993. Calculating soil nutrient balances in Africa at different scales. 1. Supra-national scale. Fertilizer Res., 35: 227-235.
8. Moisier, A.R., J.K. Syers and J.R. Freney, 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, pp: 296.
9. Banziger, M., H.R. Lafitte, G.O. Edmeades, F.J. Betran D.L. Beck and A. Elings, 1997. Recent advances for tolerance to low nitrogen in tropical maize. In Strategy for sustainable maize production in West and Central Africa. (Ed. Badu-Apraku, B.). Proceedings: Regional Maize Workshop 21-25th April. Benin Republic, IITA-Cotonou., pp: 1-34.
10. Scholberg, J., B. McNeal, K.J. Boote and J.W. Jones, 2000. Nitrogen stress effects on growth and nitrogen accumulation by field-grown tomato. Agron. J., 92: 159-167.
11. Cassman, K.G., S. Peng, D.C. Olk, J. Ladha, W. Reichardt, A. Dobermann and U. Sigh, 1998. Opportunities for increased nitrogen use efficiency from improved resource management in irrigated rice systems. Field Crop Res., 56: 7-38.

12. Smil, V., 1999. Nitrogen in crop production. An account of global flows. Global Biogeochem. Cycles, 13: 647-662.
13. Oenema, O. and S. Pietrzak, 2002. Nutrient management in food production: Achieving agronomic and environmental targets. Ambio., 31: 159-168.
14. Dobermann, A. and K.G. Cassmann, 2004. Environmental dimensions of fertilizer nitrogen: What can be done to increase nitrogen use efficiency and ensure global food security. In: Agriculture and the nitrogen cycle: Assessing the impacts of fertilizer use on food production and the environment (SCOPE 65). (Mosier *et al*. Eds.). Island Press, London, pp: 260-278.
15. Krupnik, T.J., J. Six, J.K. Ladha, M.J. Paine and C. van Kessel, 2004. An assessment of fertilizer nitrogen recovery by grain crops. In: Agriculture and the nitrogen cycle: Assessing the impacts of fertilizer use on food production and the environment (SCOPE 65). (Mosier *et al*. Eds.). Island Press, London, pp: 193-208.
16. IAEA (International Atomic Energy Agency), 2003. Management of crop residues for sustainable crop production. IAEA TECHDOC-1354 Vienna Austria. International Atomic Energy Agency.
17. Baligar, V.C., N. Fageria and Z. He, 2001. Nutrient use efficiency in plants. Commun. Soil Sci. Plant Anal., 32: 921-950.
18. Agele, S.O., B.S. Ewulo and K. Oyewusi, 2005. Effects of some soil management systems on soil physical properties, microbial biomass and nutrient distribution under rainfed maize production in a humid rainforest alfisol. Nutrient Cycling in Agroecosystems (Kluwer)., 72: 121-134.
19. Keeney, D.R. and W. Nelson, 1982. Nitrogen Inorganic Forms. In: Methods of Soil Analysis Part 2. Chemical and Microbiological Properties. Agronomy Monograph No. 9 2nd Edn., Page *et al*. Eds. Am. Soc. Agron. (Madison. W.I.), pp: 643-698.
20. Snedecor, G.W. and W.G. Cochran, 1989. Statistical Methods 7th Edn., Iowa State Press, Iowa.
21. Steel, R.G.D., J.H. Torie and D.A. Dickey, 1997. Principles and Procedures of Statistics. 3rd Edn. McGraw-Hill, New York, pp: 666.
22. Maynard, D.N., A.V. Barker, P.L. Minotti and N.H. Peck, 1976. Nitrates accumulation in vegetables. Adv. Agron., 28: 71-118.
23. Pavlovic, R., D. Stevanovic and M. Kresovic, 1996. Effect of growing method and lettuce fertilization on nitrate content in leaf. ISHS 1st Balkan Symposium on Vegetables and Potatoes. Acta Hortic., 443: 885-890.