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RESEARCH ARTICLE

PERFORMANCE AND PRODUCTIVITY OF COMPONENT CROPS IN LEGUME-UPLAND RICE INTERCROPPING SYSTEM AS INFLUENCED BY ZINC RATE

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Abstract

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The application of zinc to some selected legumes (cowpea - *Vignaunguiculata* L. Walp., soybean – *Glycine max* L. Merr. or mungbean - *Vigna radiate* L. Wilczek) intercropped with upland rice (*Oryzaesativa*L.) may improve the presence of residual nitrogen in the cropping system andprotein in-take of farmers faced with protein and mineral deficiency, especially zinc in their daily food menu. Information on the effect of zinc on legumes and rice is inadequate. The study investigated zinc rate effectsonshoot zinc status, grain yieldand productivity of the crop species in sole and intercrop with upland rice. There were three separate trials laid out in a randomised complete block design with three replications. Zinc rate (0, 2, 4 and 6 Kg•ha^{-1}) were applied to the sole and intercrop in the trials. Intercropping legumes with rice exhibited a high degree of complementarity. On average, 2 Kg Zn•ha^{-1} gave the highest total land equivalent ratio (LER; 1.89) in soybean/rice, followed by 4 Kg Zn•ha^{-1} (LER; 1.64) in mungbean/rice compared to other zinc rates.The application of 6 Kg Zn•ha^{-1} in cowpea/rice intercrop gave the highesttotal gross monetary and net returns (NR) but lowest benefit–cost ratio (BCR) compared to the other trials at the same Zn rate.In mungbean/rice intercrop,highest NR (₦263692:77•ha^{-1})and BCR(0.90) were exhibited at 4 Kg Zn•ha^{-1}. The application of 4 or 6 Kg Zn•ha^{-1}in intercropping to the selected legumespecies with upland rice enhanced productivity and financial returns in the systems.

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Introduction:-

Intercropping, which involves growing two or more crops together at the same time on the farmland in a cropping season (Ouma et al., 2010; Mbah et al., 2011;Muoneke et al., 2012) is a farming practice that is prevalent in most developing countries where farmers cultivate on marginal lands.Hossain et al. (2008) submitted that intercropping is

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more productive and efficient than sole cropping as well as ecological friendly andsustainable. The system also encourages diversified food produce and yield bonus from less expanse of land which is achievedthrough efficient use of growth resources (Muoneke, 2017). According to Liet al. (2003), most studies on intercropping are focused on legume-cereal or root crops. Legumes in cereal-based intercropping are better alternatives for security of nitrogen economy and increased yield of the component crops as well as greater productivity per unit area and higher financial returns relative to sole cropping (Thayamini and Brintha, 2010). Grain legumes such as cowpea (*Vignaunguiculata* L.Walp.), soybean (*Glycine max*[L.] Merr.) or mungbean (*Vignaradiata* L.Wilczek) are good sources of protein for human diet and atmospheric nitrogen fixers in the soil (Fageria et al., 2003; Agugo, 2003), hence play a veritable role in intercropping system.

Field crop legumes and upland rice (*Oryzae Sativa*L.) are susceptible to soil Zn deficiency, which invariably leads to Zn-deficient food produce (Gibbson, 2006).Micro-nutrients such as zinc in the form of Zn^{2+} enhance crop production because it plays a crucial role in metabolic activities associated with physiological growth and development of plants (Baybordi, 2006; Mousavi et al., 2013; Yadavi et al., 2014). Also, its presence in living systems facilitate protein creation, the maintenance of functional and structural integrity of biological membranes, gene expression, and production of energy, Krebs cycle and enzymes structure. According to Yosefi et al. (2011) zinc is required in plants in minute but critical concentrations to enhance the functionality of most physiological processes in plants.Results from previous studies by Sillanpää (1982), Ali et al. (2008) and Mousavi et al. (2013)have shown that most soils aredeficient in zinc leading to low grain yields and reduction in the nutritionalquality of farmcrop produce.The improvement in legume and cereal crop yield and its quality is a key factor in crop development in the tropics. According to Gibbson (2006), zinc deficiency has strong effecton the health of childrenbetween the ages of zero and five years old, and on women of reproductive age. Therefore, anapproach aimed at avoiding and alleviating zinc deficiency in humans include the use of zinc supplements and bio-fortification through the introduction of the micro-nutrient in cereal-legume intercrop.However, there is inadequate information on the effect of zinc on the performance of different legumes in intercrop with upland rice. Therefore, theobjectives of the study were to determine the effect of zinc rates on theperformance, grain yield and productivity of some selected legumes (cowpea, soybean or mungbean) in sole and intercrop with upland rice.

Materials and Methods:-

Three sets of trialswereconducted in 2019 cropping season at Michael Okpara University of Agriculture, Umudike (05° 29' N, 07° 33' E, 122 masl), south east Nigeria. The area is characterized by a long rainy season (April - July) and short rainy season (September – October) while the dry season commences in November and ends in March of the succeeding year (Table 1). Prior to planting of the component crops of the trials, soil samples were randomly collected from different locations of the trial site with the aid of a soil auger at the depth of 0 - 30 cm. A sub-sample was collected and subjected to analysis following standard laboratory procedures for information about the nutrient status of the soil before the application of the zinc treatment. The soil of the trial site is sandy loam of low fertility and classified as ultisol (Table 2).

Table 1:- Some meteorological data[1] of the trial site (2019 cropping season).

Month	Air temperature (ºC)	Relative humidity (%)(0900hrs.)	Number of rain days	Amount of rainfall (mm)
January	35	65	2	38.7
February	34	69	4	80.9
March	34	84	5	68.7
April	36	79	10	137.1
May	32	77	13	355.7
June	29	76	21	459.4
July	28	90	20	590.3
August	30	89	15	206.6
September	27	88	17	635
October	31	78	14	367.3
November	31	75	3	134
December	32.5	72	0	00

Source: [1]Meteorological unit, National Root Crops Research Institute, Umudike, Nigeria.

Table 2:- Some physico-chemical properties of the top soil (0-30 cm) of the trial site (2019 cropping season).

Soil properties	**Values**
Soil pH (soil:water)	4.50
Total N (%)	0.09
Organic matter (%)	2.42
Organic C (%)	1.29
Available P ($mg \cdot kg^{-1}$)	57.3
Zn ($mg \cdot kg^{-1}$)	0.45
Exchangeable cations ($cmol \bullet kg^{-1}$)	
Ca^{2+}	3.40
Mg^{2+}	2.10
K^{+}	0.28
Na^{+}	0.19

Trial 1: Cowpea+upland rice intercropping system:
The trial treatments consisted of four rates of zinc (0, 2, 4 and 6 $Kg \bullet ha^{-1}$) applied to sole cowpea, sole upland rice and intercropped cowpea+upland rice.The treatments were arranged in a randomized complete block with three replications.

Trial 2: Soybean+upland rice intercropping system:
The trial treatments consisted of four rates of zinc (0, 2, 4 and 6 $Kg \bullet ha^{-1}$) applied to sole soybean, sole upland rice and intercropped soybean+upland rice. The treatments were arranged in a randomized complete block with three replications.

Trial 3: Mungbean+upland rice intercropping system:
The trial treatments consisted of four rates of zinc (0, 2, 4 and 6 $Kg \bullet ha^{-1}$) applied to sole mungbean, sole upland rice and intercropped mungbean+upland rice. Theexperimental treatments were arranged in a randomized complete block with three replications.

The upland rice (FARO 57)used was obtained from National Cereals Research Institute, Badeggi, Nigeria while mungbeanwas secured from the Crop Technical Unit, Michael Okpara University of Agriculture, Umudike, Nigeria. Cowpea (Sampea 7) and soybean (TGx 1485-1D) seeds were obtained from Ahmadu Bello University, Zaria, Nigeria. The experimental site was plowed after clearing and the treatment plots, 4.2 × 2.5 m (10.5 m^2) marked out. The sowing beds were made as marked out leaving pathways of 50cm and 100cm between plots and blocks, respectively.Before sowing, basal application of poultry droppings was done at the rate of 2 $t \bullet ha^{-1}$. The upland rice and legume seeds were sown 20thJuly, 2019 and thinning to the desired plant population done at two weeks after emergence. Sowing of the seeds was done in strips along the length of each experimental plots.Upland rice was sown at 20 × 20 cm (sole) and 20 × 40 cm (intercrop), which was equivalent to 500,000 and 250,000 $plants \bullet ha^{-1}$, respectively. Cowpea was sown at25 × 40 cm (sole) and 40 × 40 cm (intercrop), which was equivalent to 100,000 and 62,500 $plants \bullet ha^{-1}$, respectively while soybean and mungbean were sown at 20 × 20 cm (sole) and 20 × 40 cm (intercrop), which was equivalent to 250,000 and 125,000 $plants \bullet ha^{-1}$, respectively.

The experimental field was kept weed free manually with first weeding at three and the second at six weeks after sowing. Split application of compound fertilizer (N27:P13:K13) was done immediately after the corresponding weeding regimesat the rate of 400 $Kg \bullet ha^{-1}$ to the component crops by banding method to all the treatments in the experiments.The zinc micronutrient, in the form of Zinc sulphate ($ZnSO_4 \bullet 7H_2O$) substance was mixed with the compound fertilizer and applied to the corresponding treatment plots according to treatment allocation.Leaf damaging insectswere controlled with the aid of Cymbush (Cypermethrin–Lambdacyhalothrine, 12.5 %,emulsifiable concentrate [EC.] active ingredient) at the recommended rate of 2.5 $mL \bullet L^{-1}$of water(Omotunde, 1996). The application was done at 2-week intervals with a knapsack sprayer beginning at 30 days after sowing. The application was stopped after the flower buds had formed on the legume crops.Also, netting was done round the farm and traps set to control rodents.Scare-crows and other bird scaring techniques were used to control birds from the farm.

Plant sampling was done destructivelyand growth data collected from three plants in the net-plots at 8 weeks after planting (WAP).The individual legume plants were carefully dug out and the number of nodules in the roots obtained by counting. Above ground dry matter (AGDM) of the cropspecies was obtained after being oven-dried in alaboratory oven (Sheldon Manufacturing, Cornelius, OR) at 65 ^{o}C. The weight of completely dried samples wasrecorded after the samples were weighed and re-weighed with the aid of a weighing scale (Ohaus 2000 g, Seoul, Korea)until a constant weight was achieved and expressed in g•plant^{-1}.

The relative growth rate (RGR), which is a measure of the increase in size or mass of the crop species over a period of time according to Radford(1967) was obtained with the formula:Relative Growth Rate (RGR) = W2 – W1 / W1 (T2 – T2), [g•g^{-1}•d^{-1}], where, W1, W2 are the dry matter accumulation of crop species at unit times T1 and T2.

The AGDMof the component cropspeciesin the trials were used to determine the amount of zincin the plant using the dry ash extraction method (Shuman, 1985).

The plant samples dried in the oven were ground into a fine powderwith the aid of a Wiley mill. The samples were later digested in a mixture of 2:5:1 tri-acid, [Nitric acid (HNO3): Perchloric acid (HClO4): Sulphuric acid (H_2SO_4)] mixture in a Teflon crucible and then heated on a hot plate. Zinc concentration in the obtained digest was estimated in a clear aliquot with an Atomic Absorption Spectrophotometer (AAS) model AA500 (PG Instrument, Leicestershire, England).The absorbance value on the wave-length was read and recorded as it corresponds to zinc (213.8 nm).A standard solution of zinc was also prepared and read on the AAS and the amount of zinc calculated with the formular:

Zn (mg•100 g^{-1}) = Concentration of solution (mg•L^{-1} × mL of sample) / Sample weight × 1000.

The concentration of zinc in the shoot was calculated as the product of zinc concentration and shoot dry matter (mg•kg^{-1}) according to Zhu et al. (2001).

Harvesting of the crop species was done from the net plots. The legume component crop species (cowpea, soybean and mungbean) were harvested according to Wright and Lenssen (2013) when colour of the pods had turned from green to brown.The harvested pods were further dried under shade for 14 days before threshing of the seeds was done. Grain harvesting of upland rice was done when 80 % of the whole plant had turned straw-colour and later threshed. The grain yields of the crop species were determined and extrapolated to a hectare.

Productivity:
The productivity of sole and intercrop systems of the component crops was calculated.The land equivalent ratio (LER) was computed with the formula: LER = (Yxi/Yxs) + (Yyi/Yys), Willey (1979), where, Yxi = yield of component crop species 'x' in intercrop, Yxs = yield of component crop species 'x' in sole crop, Yyi = yield of component crop species 'y' in intercrop, Yys = Yield of component crop species 'y' in sole crop. The gross monetary return (GMR) was calculated on current farm-gate price of yields of the test crop species.The total variable cost of production (TVCP) (N•ha^{-1}) was determined from all the operational expenses incurred including costs of land preparation, planting seeds, fertilizer, agro-chemical, farm labour used during planting, weed control, harvesting and preliminary processing of crop yield. The net return (NR) (N•ha^{-1}) was obtained by subtracting TVCP of the crop treatments from their respective GMR. The benefit–cost ratio (BCR)of thetreatments was calculated from the ratio of NR to TVCP.

Statistical analysis:-

All data from each crop were separately analysedusing analysis of variance for complete blocks with GENSTAT statistical package for Windows (4th ed. GENSTAT, Rothamstead Experimental Station, Hempshire, Hertfordshire, UK). The significant means were separated using least significant difference($P \leq 0.05$) as outlined by Obi (2002).Pearson's correlation analysis was done with the aid of SPSS Version 17 for windows.

Results:-

The analysis of variance (ANOVA) of cowpea/rice intercropping system (Table 3) indicated that zinc rate significantly ($P<0.05$) affected all the variables investigated (above ground dry matter (AGDM), number of cowpea nodules•plant^{-1}, relative growth rate (RGR) and shoot zinc content (mg•kg^{-1}), shoot zinc concentration (mg•plant^{-1}) and grain yield of cowpea and upland rice. Except shoot zinc concentration, crop species significantly affected all the tested variables while the main effect, cropping system affected only number of cowpea nodules•plant^{-1} and grain yield of component

crops. Zinc rate (Z) × crop species (S) interaction exhibited significant effect on AGDM, number of cowpea nodules•plant^{-1}, shoot zinc content (mg•kg^{-1}) and grain yields while Z × C interaction affected only grain yield of component crops. The interaction of S × C significantly affected AGDM, number of cowpea nodules•plant^{-1} and grain yields of cowpea and upland rice while Z × S × C interaction affected only the grain yield of the component crop species.

Results of ANOVA of soybean/rice intercropping system indicated the main effect (zinc rate) significantly affected all the tested variables (AGDM, number of soybean nodules•plant^{-1}, RGR, shoot zinc content (mg•kg^{-1}), shoot zinc concentration (mg•plant^{-1}) and grain yield of soybean and upland rice while crop species (S) had no significant ($P>0.05$) effect on shoot zinc concentration only in contrast to the other tested variables. The main effect cropping system (C) exhibited significance only on grain yields of component crops while Z × S interaction affected only number of soybean nodules•plant^{-1} and grain yields of soybean and upland rice. Except Z × C and Z × S × C interactions, S × C interaction had significant effect on grain yield of the crop species only.

The ANOVA results, showed that zinc rate had significant ($P<0.05$) effect on all the variables investigated while crop species affected only number of mungbean nodules•plant^{-1} and grain yield of mungbean and upland rice in the intercrop.

Table 3:- Analysis of variance showing sources of variation and error mean squares for zinc rate, crop species, cropping system and their interactions on performance of component crops in legume/upland rice intercropping systems showing.

Crop Mixtures	Characters	Sources of variation						
		Zinc rate (Z)	Crop species (S)	Croppin g system (C)	Z × S	Z × C	S × C	Z × S × C
Expt 1	AGDM	<0.001***	<0.001***	0.234ns	0.028*	0.418ns	0.116*	0.218ns
Cowpea + upland rice	Number of nodules•plant^{-1}	<0.001***	<0.001***	0.135*	<0.001*	0.229ns	0.135*	0.229 ns
	RGR	<0.001***	<0.001***	0.686ns	0.827ns	0.774 ns	0.148ns	0.505 ns
	Shoot Zn content	<0.001***	<0.001***	0.332ns	0.020*	0.693 ns	0.170ns	0.544 ns
	Shoot Zn Concentration	<0.001***	0.671ns	0.497ns	0.815ns	0.799 ns	0.945ns	0.922 ns
	Grain yield	<0.001***	<0.001***	0.135*	<0.001**	<0.001***	0.051*	<0.001***
Expt 2	AGDM	<0.001***	<0.001***	0.762ns	0.076ns	0.894 ns	0.302ns	0.936 ns
Soybean + upland rice	Number of nodules•plant^{-1}	<0.001***	<0.001***	0.489ns	<0.001**	0.508 ns	0.489ns	0.508 ns
	RGR	<0.001***	<0.001***	0.937ns	0.263 ns	0.866 ns	0.322ns	0.969 ns
	Shoot Zn content	<0.001***	<0.001***	0.706ns	0.493 ns	0.945 ns	0.612ns	0.929 ns
	Shoot Zn Concentration	<0.001***	0.297ns	0.956ns	0.545 ns	0.709 ns	0.510ns	0.850ns
	Grain yield	0.003*	<0.001***	0.069*	0.054*	0.981 ns	0.002*	0.757ns
Expt. 3	AGDM	<0.001***	0.265ns	0.084*	0.591ns	0.458 ns	0.454ns	0.551 ns
Mungbean +upland rice	Number of nodules•plant^{-1}	<0.001***	<0.001***	0.559ns	<0.001**	0.527 ns	0.559ns	0.527 ns
	RGR	<0.001***	0.676ns	0.162ns	0.508ns	0.565 ns	0.696ns	0.566 ns

	Shoot Zn content	<0.001***	0.308ns	0.208ns	0.480ns	0.515 ns	0.943ns	0.548 ns
	Shoot Zn Concentration	<0.001***	0.995ns	0.152*	0.725ns	0.447 ns	0.412ns	0.601 ns
	Grain yield	<0.001***	<0.001***	<0.001***	0.365ns	0.466 ns	0.033*	0.813 ns
*, *** significant at 5%. (P≤0.05) or (P≤0.001), ANOVA. F-prob.: F-probability. AGDM, Above ground dry matter. RGR, Relative growth rate.								

Cropping system main effect significantly affected AGDM, shoot zinc concentration (mg•plant^{-1}) and grain yield of component crops. The interactions of Z × S and S × C significantly affected number of mungbean nodules•plant^{-1} and grain yield of the crop species, respectively while Z × C and Z × S × C interactions had no significant (P>0.05) effect on all the tested variables.

Zinc rate applied at 6 Kg Zn•ha^{-1} significantly (P>0.05) increased AGDM and RGR (Figure 1a) as well as shoot zinc concentration and number of cowpea nodules•plant^{-1} (Figure 1b) as compared to the other zinc rates, irrespective of crop species and cropping system used in the study. The interaction of zinc rate (Z) × crop species (S) (Figure 1c) indicated that the application of 6 Kg Zn•ha^{-1} to the crop species (cowpea and upland rice) gave the highest shoot zinc content (mg•kg^{-1}) in cowpea crop species compared with upland rice at the same zinc rate and with the other interactive treatments. S × C interaction significantly affected AGDM of the component crop species (Figure 1d) and number of cowpea nodules•plant^{-1} (Figure 1e).Furthermore, theinteraction indicated that intercropped cowpea and upland rice crop species exhibited the highest AGDM, which was higher by 18 and 10 %, respectively relative to their corresponding sole crop species while intercropped cowpea species had the highest number of cowpea nodules•plant^{-1} (avg. 17.58) relative to its corresponding sole crop species (avg. 15.58). The three-way interaction of Z × S × C affected grain yields of the component crops (cowpea and upland rice) (Figure 1f). The effect of the interaction indicated an increase in grain yield as zinc rate increased from zero to the highest amount used in the study in both sole and intercrop. According to the analysis of variance, sole cowpea that received 6 Kg Zn•ha^{-1}gave significantly the highest grain yield (avg. 5,330 Kg•ha^{-1}) compared with its corresponding intercrop yield (avg. 4,907 Kg•ha^{-1}) as well as grain yields obtained from the upland rice in both sole (avg. 1,710 Kg•ha^{-1}) and intercrop (avg.1,353 Kg•ha^{-1}). Grain yield in sole crop upland rice was higher than in its corresponding intercrop. Also, the results showed that between the component crop species investigated, cowpea gave the highest RGR (avg. 0.980 g^{-1}•m^{-2}•day^{-1}) compared with upland rice (avg. 0.417 g^{-1}•m^{-2}•day^{-1}).

The application of 6 Kg Zn•ha^{-1} gave the highest RGR and shoot zinc content (Figure 2a) as well as grain yield in soybean and upland ricecomponent crop species, and shoot zinc concentration (Figure 2b) relative to the other zinc rates studied, irrespective of crop species and cropping system. Z ×S interaction showed that the application of 6 KgZn•ha^{-1} gave the highest AGDM in the component crops compared with the other zinc treatments while zero zinc application gave the least values (Figure 2c). Also, the highest number of soybean nodules•plant^{-1} (Figure 2d), which was recorded at the Zn application rate of 6 Kg•ha^{-1} was higher by 71, 46 and 32 % relative to 0, 2, and 4 KgZn•ha^{-1} applied to the legume component crop species. Results from the analysis of variance indicated that the crop species (soybean) exhibited higher RGR (avg. 0.64 g^{-1}•m^{-2}•day^{-1}) and shoot zinc content (avg. 0.159 mg•plant^{-1}) relative to upland rice crop species with RGR (avg. 0.039 g^{-1}•m^{-2}•day^{-1}) and shoot zinc content

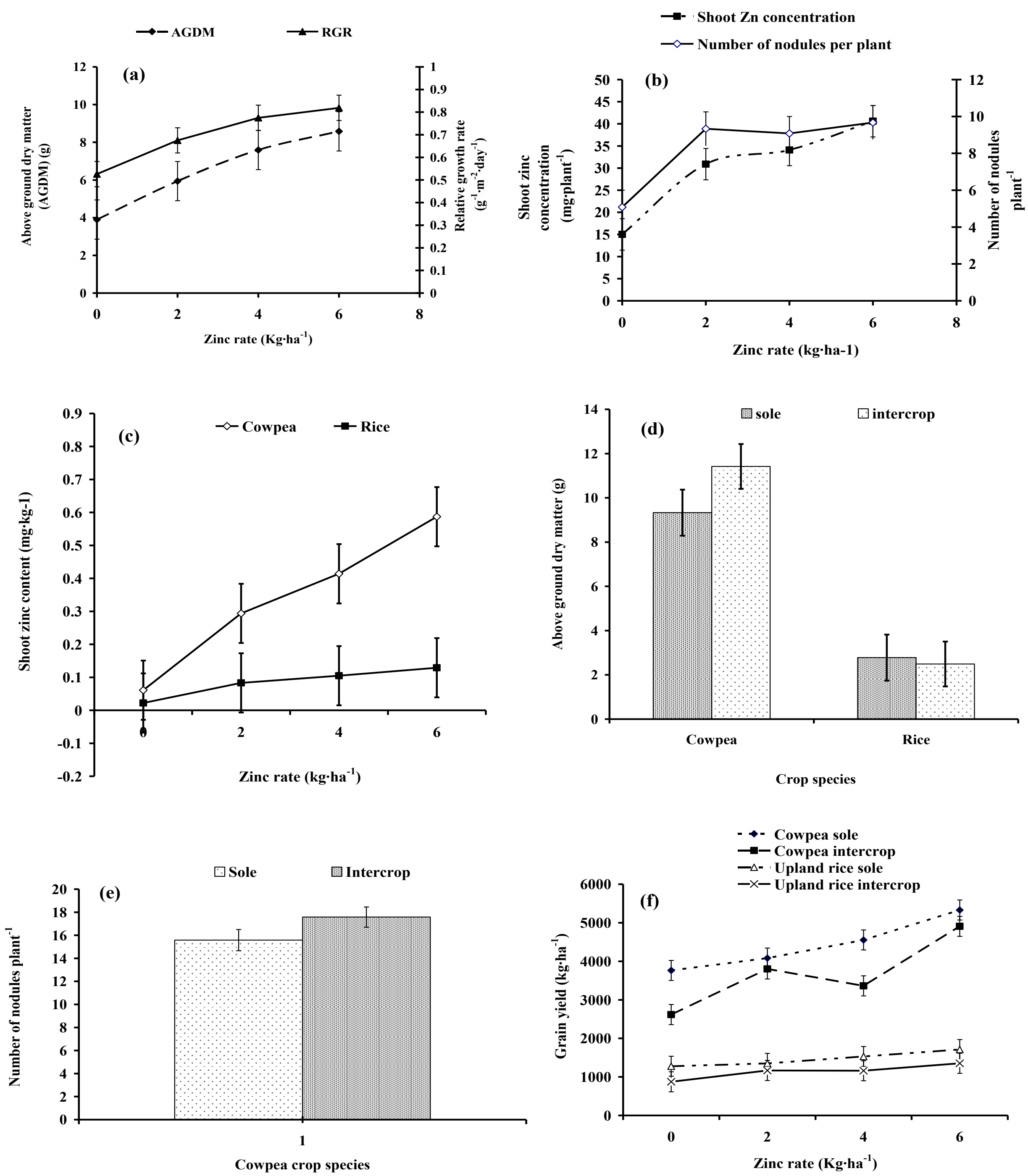

Figure 1:- Effect of zinc rate on above ground dry matter and relative growth rate,and on shoot zinc concentration and number of cowpea nodules•plant^{-1}of component crops in cowpea/upland rice intercrop.Zinc rate × crop species interaction effect on shoot zinc content of component crops in cowpea/upland rice intercrop.Crop species× cropping systeminteraction effect on above ground dry matter andon number of cowpea nodules•plant^{-1}of in cowpea/upland rice intercrop.Zinc rate × crop species × cropping system interaction effect on grain yield of cowpea and upland rice in cowpea/upland rice intercrop.The error bars indicate the standard error of differences between means (SED).

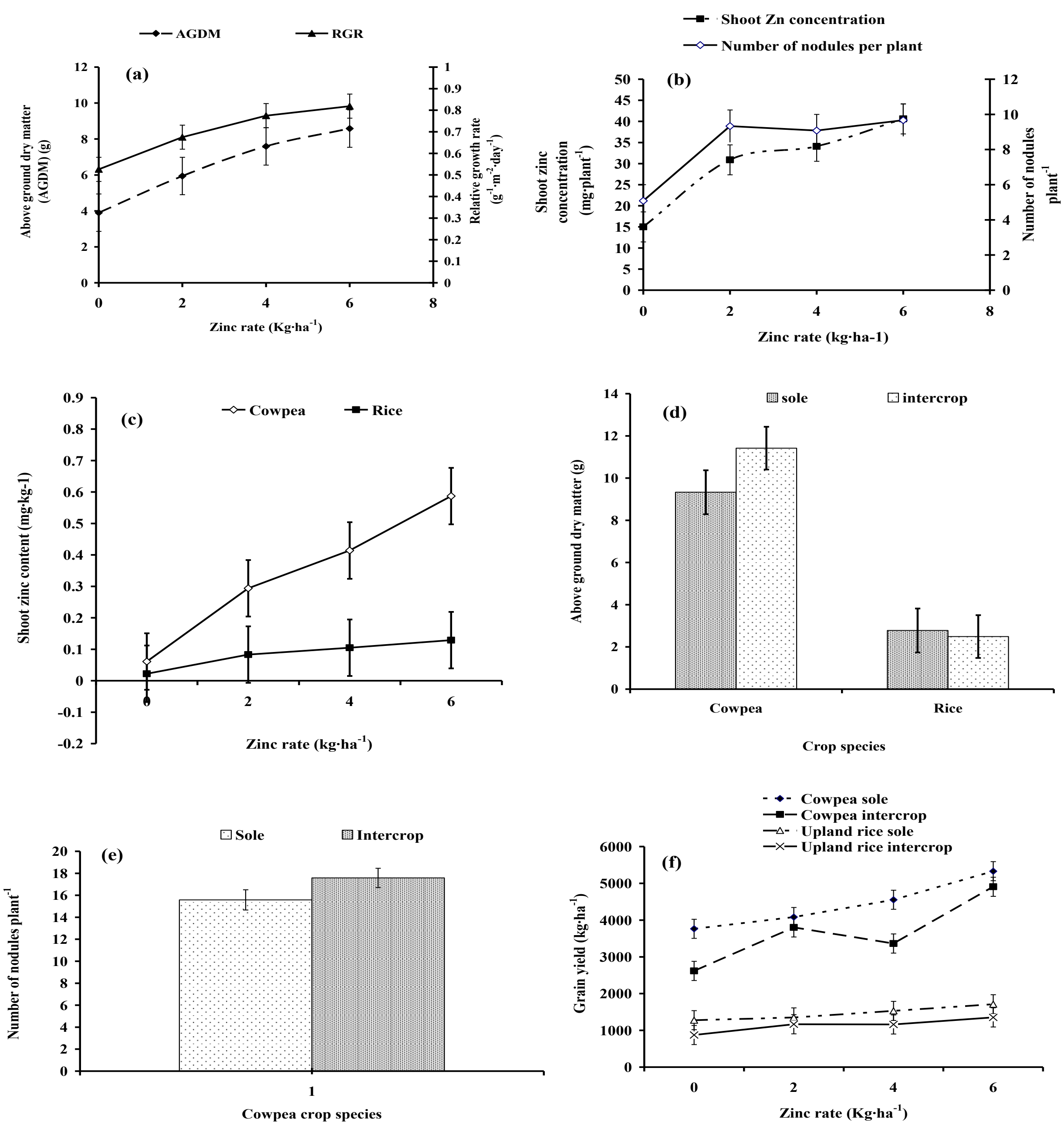

Figure 2:- (a) Effect of zinc rate on relative growth rate and shoot zinc content, and (b) on grain yield and shoot zinc concentrationof component crops in soybean/upland rice intercrop.(c) Zinc rate × crop species interaction effect on above ground dry matter of soybean and upland rice, and (d) on number of cowpea nodules•plant^{-1}in soybean/upland rice intercrop. The error bars indicate the standard error of differences between means (SED).

(avg. 0.085 mg•plant^{-1}) regardless of zinc rate and cropping system. Also, the interaction of S ×C indicated that sole soybean had the highest grain yield (avg. 1467 Kg•ha^{-1}) as compared to the corresponding intercrop (avg. 1138 Kg•ha^{-1}) while sole upland rice gave grain yield (avg. 667 Kg•ha^{-1}) that was higher by 149 % relative to its intercrop yield (avg. 574 Kg•ha^{-1}).

Irrespective of crop species and cropping system, the application of 6 Kg Zn•ha^{-1} gave the highest AGDM and shoot zinc concentration (Figure 3a), RGR and shoot zinc content (Figure 3b) of the component crops compared to the other zinc rates studied in mungbean/upland rice intercrop. Also, zinc rate at 6 Kg Zn•ha^{-1} gave the highest grain yield in the component crop species (Figure 3c) irrespective of cropping system relative to the other zinc rates studied, especially 0 Kg Zn•ha^{-1} which had the least values in all the variables tested. The results further showed that Z ×S interaction effect (Figure 3d) increased the number of mungbean nodules•plant^{-1}, which ranged from 2.5 (0 Kg Zn•ha^{-1}) to 6.17 (6 Kg Zn•ha^{-1}). Also, crop species (S) ×cropping system (C) interaction (Figure 3e) indicated that sole crop upland rice gave the highest grain yield (1467 kg•ha^{-1}) followed by its corresponding intercrop yield (1138 kg•ha^{-1}) compared to grain yield of sole crop mungbean (457 kg•ha^{-1}) and its corresponding intercrop grain yield of 307 kg•ha^{-1}. The grain yields of sole upland rice and mungbean were higher by 22 and 33 %, respectively relative to their corresponding intercrop yields. The relationship between zinc rate and grain yield of the component crops was linear and positive (f), which indicated an increase in grain yield of mungbean and upland rice as the zinc rate applied increased from zero to the highest amount (6 Kg Zn•ha^{-1}) used in the study. According to the analysis of variance, irrespective of zinc rate and crop species used, sole cropping system exhibited the highest amount of AGDM (avg. 3.06 g) as compared to the intercrop system (avg. 2.54 g). However, the trend was not the same in shoot zinc concentration in which sole cropping system exhibited lower shoot zinc concentration (avg. 28.9 mg•plant^{-1}), which was lower by 11 % relative to the intercrop (avg. 32.5 mg•plant^{-1}).

Pearson's correlation analysis between all the pairs of variables in cowpea crop species (Table 4) indicated that grain yield of cowpea had positive and significant ($p>0.05$) correlation with RGR, Shoot Zn Concentration and Shoot Zn content with correlation coefficients (r) of 0.44, 0.61 and 0.49, respectively. AGDM, RGR and Shoot Zn Concentration exhibited significantly ($p>0.01$) strong and positive correlations amongst themselves. The results from correlation analysis of soybean attributes indicated that except grain yield of soybean, the other variables (AGDM, RGR, Shoot Zn Concentration and Shoot Zn Content) exhibited highly significant and positive correlation amongst themselves.

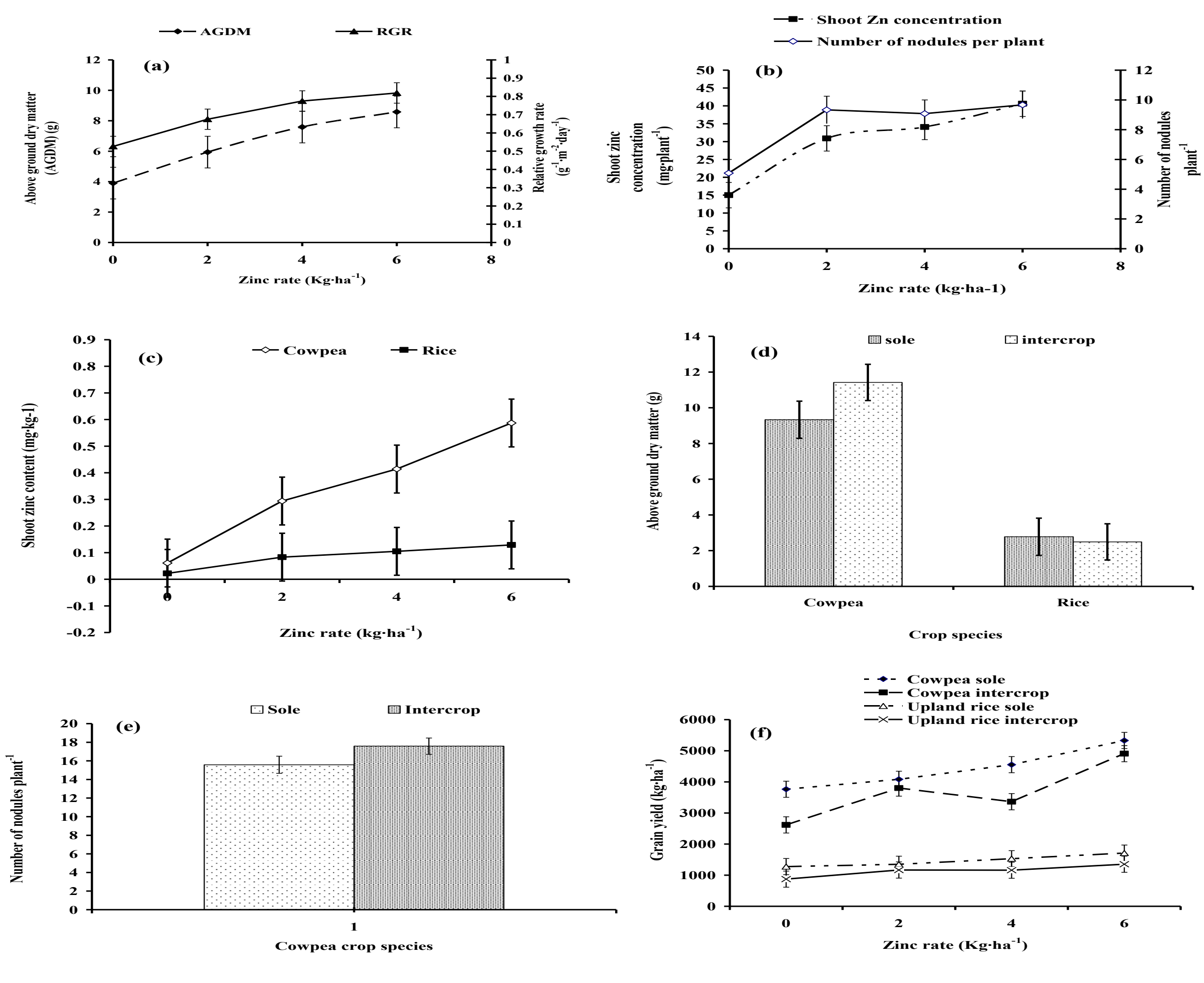

Figure 3:- (a) Effect of zinc rate on above ground dry matter and shoot zinc concentration, (b) on relative growth rate and shoot zinc content of component crops in mungbean/upland rice intercrop. (c) Effect of zinc rate on grain yield of component crops, and (d) number of mungbean nodules•plant^{-1} in mungbean/upland rice intercrop. (e) Crop species × cropping system interaction effect on grain yield of mungbean and upland rice in intercrop. (f) The relationship between zinc rate and grain yields of component crop species in mungbean/upland rice intercrop with linear regression. The error bars indicate the standard error of differences between means (SED).

The correlation analysis of mungbean indicated that grain yield of mungbean crop species and the other variables (AGDM, RGR and Shoot Zn content) was significant, high and positive. All the other characters also exhibited significant ($p>0.05$) and positive relationship among themselves.Except Shoot Zn Concentration and Shoot Zn content, results from the correlation analysis of upland rice characters indicated that grain yield of the crop species exhibited significant ($p>0.05$) and positive association with AGDM and RGR with correlation coefficients (r) of 0.41 and 0.44, respectively. The other variables exhibited highly significant ($p>0.01$) and positive association amongst themselves.

The productivity of cowpea/upland rice, soybean/upland rice and mungbean/upland rice intercropping systems (Table 5) showed that total LERs in the three trials were all above unity, an indication that intercropping had advantage compared to sole crop system. In cowpea/upland rice intercrop, the application of 6 Kg Zn•ha^{-1} had the highest total LER followed by 4 Kg Zn•ha^{-1}, however, the trend was not the same in soybean/upland rice and mungbean/upland rice intercropping systems. In the three trials, 0 Kg Zn•ha^{-1} gave the lowest total LER. The partial gross monetary returns (GMRs) calculated for cowpea, soybean, mungbean and upland rice crop species were higher in sole cropping as compared to their corresponding intercrop. However, total GMRs for the component crop species in the intercropping systems were higher when compared with their corresponding sole cropped equivalents. Among intercrops in the three trials, the application of 6 Kg Zn•ha^{-1} gave the highest TGMR while 0 Kg Zn•ha^{-1} gave the lowest financial returns. The application of 6 Kg Zn•ha^{-1} to soybean/ upland rice and mungbean/upland rice intercrops gave low LER but high GMR, which showed that higher LER does not automatically relate to higher GMR in intercropping. The results further showed that total variable cost of production, (TVCP) in intercropping was higher compared with sole cropping in the three trials. The highest TVCP in all the trials was recorded under 6 Kg Zn•ha^{-1}. Among treatments in cowpea/upland rice and soybean/upland rice intercrops, the application of 6 Kg Zn•ha^{-1} gave the highest net return (NR) while 4 Kg Zn•ha^{-1} gave highest NR in mungbean/upland rice intercrop. The benefit-cost-ratio (BCR) in intercropping treatments was higher compared to their corresponding sole crop treatments except for sole cropped upland rice that received 6 Kg Zn•ha^{-1}. The highest BCRs were recorded under soybean/upland rice and mungbean/upland rice intercrops while cowpea/upland rice exhibited the lowest BCR in the three intercropping trials investigated.

Table 4:- Pearson's correlation coefficients (r) of plant attributes of component crops (Cowpea, soybean, mungbean and upland rice) as influenced by zinc rate in legume/upland rice intercrop.

Plant characters	Grain yield (Mt•ha^{-1})	AGDM (g)	RGR (g^{-1}• m^{-2} •day^{-1})	Zn Concen-tration (mg•kg^{-1})		Grain yield (Mt•ha^{-1})	AGDM (g)	RGR (g^{-1}• m^{-2} •day^{-1})	Zn Concen-tration (mg•kg^{-1})
	Cowpea					**Soybean**			
Grain yield (Mt•ha^{-1})	1.00					1.00			
AGDM (g)	0.39ns	1.00				-0.01ns	1.00		
RGR (g^{-1}•m^{-2}•day^{-1})	0.44*	0.96**	1.00			-0.03ns	0.98**	1.00	
Shoot Zn Concentration (mg•kg^{-1})	0.61**	0.67**	0.69**	1.00		-0.029ns	0.55**	0.58**	1.00
Shoot Zn content (mg•plant^{-1})	0.49*	0.92**	0.87**	0.86**		-0.15ns	0.89**	0.87**	0.84**
	Mungbean					**Upland rice**			
Grain yield	1.00					1.00			

(Mt•ha^{-1})									
AGDM (g)	0.60**	1.00				0.41*	1.00		
RGR (g^{-1}•m^{-2}•day^{-1})	0.61**	0.98**	1.00			0.44*	0.98**	1.00	
Shoot Zn Concentration (mg•kg^{-1})	0.39ns	0.70**	0.76**	1.00		0.27ns	0.57**	0.60**	1.00
Shoot Zn content (mg•plant^{-1})	0.55**	0.95**	0.93**	0.86*		0.40ns	0.97**	0.90**	0.88**
*, ** significantcorrelation at0.05 and 0.01 probability levels, respectively									

Table 5:- Grain yield, land equivalent ratio (LER), gross monetary return (GMR), total variable cost of production (TVCP), net return (NR) and benefit cost ratio (BCR) of component cropspecies as influenced by zinc rate in legume/upland rice intercrop.

Treatment	Grain yield (Kg·ha^{-1})		Land equivalent ratio			Gross monetary return (₦·ha^{-1})			[5]TVCP (₦·ha^{-1})	[6]NR (₦·ha^{-1})	BCR
			Partial			Partial					
	Cowpea	Upland rice	Cowpea	Upland rice	Total	[1]Cowpea	[2]Upland rice	[3]Total			
Cowpea + upland rice intercrop											
Sole cowpea + 0 kg Zn·ha^{-1}	3763	[4]-	1.00	-	1.00	1,693,350	-	1693350	1325893	367456.95	0.28
Sole cowpea + 2 kg Zn·ha^{-1}	4083	-	1.00	-	1.00	1,837,350	-	1837350	1392711	444638.7	0.32
Sole cowpea + 4 kg Zn·ha^{-1}	4553	-	1.00	-	1.00	2,048,850	-	2048850	1419853	628996.95	0.44
Sole cowpea + 6 kg Zn·ha^{-1}	5330	-	1.00	-	1.00	2,398,500	-	2398500	1503860	894640.5	0.59
Sole rice + 0 kg Zn·ha^{-1}	-	860	-	1.00	1.00	-	352600	352600	256692.8	95907.2	0.37
Sole rice + 2 kg Zn·ha^{-1}	-	1020	-	1.00	1.00	-	418200	418200	294412.8	123787.2	0.42
Sole rice + 4 kg Zn·ha^{-1}	-	1109	-	1.00	1.00	-	454690	454690	321465.8	133224.17	0.41
Sole rice + 6 kg Zn·ha^{-1}	-	1223	-	1.00	1.00	-	501430	501430	322920.9	178509.08	0.55
Cowpea + rice + 0 kgZn·ha^{-1}	2617.0	290	0.70	0.34	1.03	1177650	118900	1296550	823309.3	473240.75	0.57
Cowpea + rice + 2 kg Zn·ha^{-1}	3802.22	313	0.93	0.31	1.24	1710999	128330	1839329	1072329	767000.19	0.72
Cowpea + rice + 4 kg Zn·ha^{-1}	3363.0	567	0.74	0.51	1.25	1513350	232470	1745820	1092883	652936.68	0.60
Cowpea + rice + 6 kg Zn·ha^{-1}	4907.0	590	0.92	0.48	1.40	2208150	241900	2450050	1516581	933469.05	0.62

Grain yield harvestat 13 % moisture content.

Yield of cowpea and upland rice at N450•kg^{-1}, and N410•kg^{-1}, respectively; (Sold at prevailing farm-gate market price).

[1]and [2]. Partial GMR for cowpea and upland rice, respectively. PGMR wascomputed as the product of each crop yield with the prevailing farm-gate market price.

[3]. Total GMR was computed as the sum of the PGMRs from cowpea and upland rice in sole or intercrop as the case may be.

[4]. No measurements were taken from the corresponding plots because the component crop (cowpea or upland rice) was not represented in that plot (sole crop).

[5]TVCP. Total cost of land preparation, seeds, fertilizer, labour for all sundry farm operations and harvesting.

[6]. Net return (NR) was the difference between TGMR and TVCP of component cropspecies in sole and intercrop while BCR is the ratio of NR and TVCP.

Table 5 Continued

Treatment	Grain yield (Kg·ha^{-1})		Land equivalent ratio			Gross monetary return (₦·ha^{-1})					
			Partial			Partial					
	Soybean	Upland rice	Soybean	Upland rice	Total	[1]Soybean	[2]Upland rice	[3]Total	[5]TVCP (₦·ha^{-1})	[6]NR (₦·ha^{-1})	BCR
Soybean + upland rice intercrop											
Sole soybean + 0 kg Zn·ha^{-1}	1506	[4]-	1.00	-	1.00	361440	-	361440	272164.3	89275.7	0.33
Sole soybean + 2 kg Zn·ha^{-1}	1533	-	1.00	-	1.00	367920	-	367920	258647.8	109272	0.42
Sole soybean + 4 kg Zn·ha^{-1}	1760	-	1.00	-	1.00	422400	-	422400	281740.8	140659	0.50
Sole soybean + 6 kg Zn·ha^{-1}	1868	-	1.00	-	1.00	448320	-	448320	297236.2	151084	0.51
Sole rice + 0 kg Zn·ha^{-1}	-	860	-	1.00	1.00	-	352600	352600	235536.8	117063	0.50
Sole rice + 2 kg Zn·ha^{-1}	-	1020	-	1.00	1.00	-	418200	418200	254683.8	163516	0.64
Sole rice + 4 kg Zn·ha^{-1}	-	1109	-	1.00	1.00	-	454690	454690	270995.2	183695	0.68
Sole rice + 6 kg Zn·ha^{-1}	-	1223	-	1.00	1.00	-	501430	501430	322920.9	178509	0.55
Soybean + rice + 0 kg Zn·ha^{-1}	1374	772	0.91	0.90	1.81	329760	316520	646280	405863.8	240416	0.59
Soybean + rice + 2 kg Zn·ha^{-1}	1509	920	0.98	0.90	1.89	362160	377200	739360	431046.9	308313	0.72
Soybean + rice + 4 kg Zn·ha^{-1}	1594	985	0.91	0.89	1.79	382560	403850	786410	449040.1	337370	0.75
Soybean + rice + 6 kg Zn·ha^{-1}	1819	1057	0.97	0.86	1.84	436560	433370	869930	513258.7	356671	0.69

Table 5 Continued

Treatment	Grain yield (Kg·ha^{-1})		Land equivalent ratio			Gross monetary return (₦·ha^{-1})					
			Partial			Partial					
	Mung bean	Upland rice	Mung bean	Upland rice	Total	[1]Mung-bean	[2]Upland rice	[3]Total	[5]TVCP (₦·ha^{-1})	[6]NR (₦·ha^{-1})	BCR
Mungbean + upland rice intercrop											
Sole mungbean + 0 kg Zn·ha^{-1}	329	[4]-	1.00	-	1.00	171,080	-	171,080	120269.24	50810.76	0.42
Sole mungbean + 2 kg Zn·ha^{-1}	405	-	1.00	-	1.00	210,600	-	210,600	154369.8	56230.2	0.36
Sole mungbean + 4 kg Zn·ha^{-1}	439	-	1.00	-	1.00	228,280	-	228,280	159111.16	69168.84	0.43
Sole mungbean + 6 kg Zn·ha^{-1}	655	-	-	1.00	1.00	340,600	-	340,600	239441.8	101158.2	0.42
Sole rice + 0 kg Zn·ha^{-1}	-	860	-	1.00	1.00	-	352,600	352,600	211912.6	140687.4	0.66
Sole rice + 2 kg Zn·ha^{-1}	-	1020	-	1.00	1.00	-	418,200	418,200	263047.8	155152.2	0.59
Sole rice + 4 kg Zn·ha^{-1}	-	1109	-	1.00	1.00	-	454,690	454,690	274632.76	180057.24	0.66
Sole rice + 6 kg Zn·ha^{-1}	-	1223	-	1.00	1.00	-	501,439	501,439	297849.42	203580.58	0.68
Mungbean + rice + 0 kg Zn·ha^{-1}	191	630	0.58	0.73	1.31	99,320	258,300	357,620	221009.16	136610.84	0.62
Mungbean + rice + 2 kg Zn·ha^{-1}	322	720	0.80	0.71	1.50	167.440	295,200	462,640	262779.52	199860.48	0.76
Mungbean + rice + 4 kg Zn·ha^{-1}	368	893	0.84	0.81	1.64	191,360	366,130	557,490	293797.23	263692.77	0.90
Mungbean +	479	933	0.73	0.76	1.49	249,080	382,530	631,610	387176.93	244433.07	0.63

rice + 6 kg Zn·ha^{-1}											

Grain yield harvest at 13 % moisture content.
Yield of cowpea and upland rice at N450•kg^{-1}, and N410•kg^{-1}, respectively. (Sold at prevailing farm-gate market price).
[1] and [2]. Partial GMR for cowpea and upland rice, respectively. PGMR was computed as the product of each crop yield with the prevailing farm-gate market price.
[3]. Total GMR was computed as the sum of the PGMRs from cowpea and upland rice in sole or intercrop as the case may be.
[4]. No measurements were taken from the corresponding plots because the component crop (cowpea or upland rice) was not represented in that plot (sole crop).
[5]. TVCP. Total cost of land preparation, seeds, fertilizer, labour for all sundry farm operations and harvesting.
[6]. Net return (NR) was the difference between TGMR and TVCP of component cropspecies in sole and intercrop while BCR is the ratio of NR and TVCP.

Discussion:-

The results of the intercropping study showed that sowing of some legumes (cowpea, soybean or mungbean) with upland rice resulted in important agronomic benefits in cowpea/upland, soybean/upland and mungbean/upland intercropping systems in the humid tropics of Umudike, Nigeria. Competition for growth resources between crop species in the intercrops varied depending on the zinc rate applied, phyllotaxy and growth pattern of the component crops in the mixes. Studies by Askegaard and Eriksen (2008) have shown that legumes act as catch crops and nitrogen fixers, hence can reduce leaching of some soil minerals.

The cowpea crop species in the mix exhibited increased AGDM and RGR compared with the other selected legumes and upland rice in the intercropping mixtures investigated. The better performance was due to stronger vigour and aggressive vegetative growth recorded under 6 Kg $ZnSO_4•7H_2O•ha^{-1}$. Also, the results showed that intercropping the selected legumes with upland rice caused an increase in grain yield in all the component crop species and in AGDM only in mungbean/upland rice intercrop. The results are in agreement with similar studies carried out in the tropical and sub-tropical agro-eco regions by Aggarwal et al. (1992) on rice/mungbean, Akanvou et al. (2002) on two contrasting legume species with upland rice and Ahmad et al. (2007) on upland rice/legume species intercrops. Zinc rate significantly affected all the crop species in sole and intercrop. In particular, zinc rate at the highest rate used in the study (6 Kg Zn•ha^{-1}) exhibited strong effect on all the variables tested in the three intercropping systems (cowpea/upland rice, soybean/upland rice and mungbean/upland rice). The results corroborate Brady and Weil (2008),Broadley et al. (2007) and Garcia et al. (2008) on zinc micronutrient in which they submitted that zinc is required by plants in small quantity, however, its availability is essential for absorption, especially in crop improvement because zinc is a strong promoter of growth hormone biosynthesis, the development of crop yield maturation and starch synthesis. The results also indicated that shoot Zn content and shoot Zn concentration in the crop species investigated increased with increase in rate (Zhang et al., 2013). Other works by Doncheva et al. (2001) and Stoyanova and Doncheva (2002) on pea plant showed that the amount of Zn in the roots, stems and leaves increased with greater Zn rates. Also, lower Zn translocation in above ground parts seemed to result from Zn complexing by organic anion in the root system. Studies by Bagci et al. (2007) indicated that crop Zn deficiency can be improved through Zn diffusion in rhizosphere by increasing Zn uptake by root, which invariably is of benefit to the shoot. Also, recent studies by Harris et al. (2007) demonstrated that Zn application can increase Zn concentration in shoots of crop species when zinc is placed by soil application. This suggests that bio-fortification of component crop species such as cowpea, soybean, mungbean and upland rice with Zn by an agronomic approach in the form of application of different rates of zinc as it applies to wheat is promising (Cakmak, 2008). Aboyeji et al. (2019) studies on groundnut found that the application of 8 Kg Zn•ha^{-1} significantly increased seed yield per hectare, and seed quality.

In the three trials, upland rice responded positively to legume intercropping in soybean and mungbean, but suffered adverse competitive effect in cowpea because of its prostrate and aggressive growth habit. According to Peters et al. (2003), a deeper root system and better adaption to marginal acid soils may have contributed to cowpea's better performance in the system. Comparing the three annual legumes (cowpea, soybean or mungbean) for fixation of atmospheric nitrogen through number of nodules•plant^{-1}, shoot zinc content and shoot zinc concentration effects on component crop (upland rice), Wortmann et al. (2000) also found that cowpea produced the most above ground dry mass and had the highest number of nodules per plant. Average grain yield of the component crop species that were applied with different zinc rates in sole and intercrop ranged from 2617 to 5330, 1374 to 1868, 191 to 655 and 290 to 1223 $Kg \bullet ha^{-1}$ for cowpea, soybean, mungbean and upland rice, respectively, indicating variations amongst the cropping systems. Similar findings were reported by Mandal et al. (1990) in rice-legumes cropping systems in India.

The selected legumes intercropped with upland rice exhibited complementarity, hence yielded higher (combined intercrop yield) than their corresponding sole crop yields. The results were in consonance with Mandal et al. (1990) in the study on a number of intercropping trials of rice and legumes under different conditions in which intercropping resulted in greater productivity per unit of land than sole crops of the intercrop component crop species. Furthermore, Joshi (2002) made similar observations in rice-based cropping system in Nepal and Ogutu et al. (2012) in rice-legume intercropping systems in Kenya. The economic benefits of the systems depicted in the form of gross monetary return, net return and benefit-cost ratio indicated higher cash returns from intercropping than growing the sole crops. The results agreed with Muoneke et al. (2007) and who reported that maize (Zea mays)/soybean intercropping was profitable than their sole crops as well as Matusso et al. (2012) on cereal-legume intercropping systems in sub-Sahara Africa. Also, the results suggested that intercropping was able to improve the overall productivity of the system as well as increase financial benefits of the component crop species, which corroborated studies by Oseni (2010) in sorghum (*Sorghum bicolor*)/cowpea intercrop.

Conclusion:-

The results indicated that zinc rate affected the selected legumes and upland rice in both sole and intercrop. The application of 6 Kg $ZnSO_4 \bullet 7H_2O \bullet ha^{-1}$gave the highest grain yields in all the component crop species and highest gross monetary returns only in cowpea/upland rice intercrop. The application of 4 Kg $ZnSO_4 \bullet 7H_2O \bullet ha^{-1}$ in soybean or mungbean intercropped with upland rice gave highest average benefit-cost ratio, hence can be adduced to be highly complementary in the system compared to cowpea/upland rice mix. The findings require validation in the form of replicating the trials to enhance recommendation.

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Conflict of interest:

The authors declare no conflicts of interest.

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