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Mitigation of Chemically Degraded Soil of Coastal Plain Sand with Biochar and Other Soil Amendments

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Abstract: *Using different amendments to ameliorate chemically degraded soil would affect the soil nutrients in different forms and ways. It was based on this assumption that an incubation study was carried out at Michael Okpara University of Agriculture Umudike, to investigate the effect of biochar and other amendments on some chemical properties of coastal plain sand in Umudike of Abia State. The study lasted for eighty four days and the treatments comprised of seven amendments namely: Control (no amendment), Biochar, Ash, Lime, Biochar + Poultry Manure, Ash + Poultry Manure and Lime + Poultry Manure. They were applied at a sole rate of 1.43g to 100g of soil. The treatments were replicated three times in a Completely Randomized Design. Soil pH, exchangeable acidity, available phosphorus, organic carbon and exchangeable calcium were determined fortnightly using the standard laboratory procedure. The result showed that applied Biochar + Poultry Manure gave the significantly ($p<0.05$) highest organic carbon value of 1.52% at the 12^{th} week of incubation over the soil pre -treatment value of 0.06%. The pH value range of between 6.1-6.7 which is near neutral was given by the applied Biochar + Poultry Manure at the weeks of the incubation. The result also showed that soil exchangeable calcium positively correlated with soil pH. Biochar + Poultry Manure seems to have great potentials in improving the soil chemical properties. Further field investigation will be conducted for the verification of these results.*

Keywords: *Coastal plain sand, biochar, chemically degraded soil and mitigation.*

1. INTRODUCTION

Fertile soils are soils that contain adequate plant essential nutrients; these include nitrogen, phosphorus and potassium. They have abundant minerals such as zinc, manganese, boron, iron, sulfur, cobalt, copper, magnesium, molybdenum and chlorine. All these nutrients and minerals help to promote plant growth and development. Other attributes of fertile soils include rich organic matter content, neutral pH and good structure with lots of microorganisms. Unfortunately most soils cannot be term fertile because of many factors that affect them negatively. Prominent among these factors is soil degradation. Soil degradation is defined as a change in the soil health status resulting in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries (FAO, 2016).

The major types of degradation that have great detrimental effect on the soil ecosystem are physical, biological and chemical degradations (Ballayan, 2000). Physical degradation includes removal of soil surface through wind and water erosion, compaction, sealing and crushing. Biological degradation involve loss of organic matter and biodiversity while chemical degradation or deterioration examples are leaching, acidity, salinity, pollution, reduction in quality of topsoil associated with nutrient decline (Mupenzi, *et al*., 2011). Causes of soil degradation include drastic weather conditions, poor soil management, industrializations and human population explosion among others. When a soil is degraded, its capacity to produce crops and sustain the lives of the soil microbes is diminished. The inability of the soil to produce food crops for the increasing population will usually lead to food shortage, which if not manage will result to malnourishments, impoverishments and restiveness.

One of the ways to mitigate soil degradation is through soil management. Soil managements are specific interventions that enhance the soil quality, protect and conserve the soil resources taking into cognizance different soil types and soil characteristics (FAO, 2016). Some of the commonest management practices are residue retention, crop rotation, cover cropping, use of fertilizer, manure and compost.

Presently the cost of procuring fertilizer which is one of the fastest soil nutrient restorers is becoming too high for the poor resource farmers to afford. The best bid is to look for alternatives that will readily replenish the soil nutrients. Using crop residues and manure as soil nutrient enhancer is not a new concept but the conversion of the crop residue into biochar and fortifying it with manure is relatively new in Southeast Nigeria, and therefore need to be investigated. It is against this back drop that the present incubation study was conducted to ascertain the ability of ash, biochar, lime and their combinations with poultry manure respectively to replenish the depleted soil nutrients.

2. Materials and Methods

The incubation study was conducted at the Department of Soil Science and Meteorology Laboratory situated at Michael Okpara University of Agriculture Umudike (05° 29` N, 07° 33` E and 122 m above sea level) for a period of eighty-four days. The climate of Umudike is essentially humid rainforest; this is because it is located within the tropical rainfall zone with a mean rainfall of 2117mm. The rainfall is distributed over nine to ten months in a bimodal rainfall pattern. These are the early rain (April -July) and late rain (August -October) with five months of dry season and a short dry spell in August and this is popularly called August break. The monthly minimum air temperature ranged from 20°C to 24°C while the monthly maximum air temperature ranged from 28°C to 35°C. The relatively humidity varies from 51% to 87%. There is a cool dry wind popularly called 'Harmattan', which blows southward from the Sahara desert. It keeps the weather cool and dry from mid of November to March. The average sunshine hours varied from 3 to 7 hours and appeared always lowest in the months of July, August and September. Sunshine hours were always highest in the month of May. (Source: NRCRI Umudike Meteorological Station, 2015) The soils used for the experiment was from coastal plain sand at the Eastern Farm of Michael Okpara University of Agriculture (05° 29` N, 07° 33` E).

Soil Sampling and Preparation

Soils were collected randomly from the marked site at the depth of 0- 15 cm. The samples were bulked, air-dried, ground, and pass through a 2 mm sieve mesh. One hundred grams of the sieved soil samples were weighed into a 500ml plastic container and labelled appropriately for the incubation study.

Treatments and Preparation

The treatments were Control (no amendment), Ash, Biochar, Lime, Ash + Poultry Manure, Biochar + Poultry Manure and Lime + Poultry Manure. They were applied at the rate of 2 ton/ha. The grams equivalent of the tones which was 1.43g was actually applied to 100g of the soils used for the incubation. For the containers that received sole amendments of Ash, Biochar and Lime, 1.43g of the treatments were applied whereas the ones that were combined received 0.72g each of the combined treatments. The Biochar and Ash were prepared from the following feed stocks; rice husk, cowpea husk and spent mushroom substrate, others were maize husk, sawdust and clay. Biochar was produced from the pyrolysis process using the pyrolysis drum at the temperature of 450°C and afterwards characterized according to biochar material test categories and characteristic IBI Biochar Standards *Version* 2.0 (2014). The lime was procured from the Ministry of Agriculture and Rural Development Abia State whereas the poultry manure was from battery cage and sourced from Michael Okpara University of Agriculture Farm Center. The chemical properties of the treatments were determined and are presented on Table 1.

Table 1. *Chemical composition of the treatments used for the experiment*

Properties	Ash	Biochar	Poultry Manure	Lime
pH	9.2	6.9	7.03	11.1
Nitrogen (%)	0.19	0.21	0.43	ND
Phosphorus (%)	1.34	3.10	4.03	0.04
Potassium (%)	0.41	0.47	0.26	2.41
Calcium (%)	38.00	23.41	10.94	57.32
Organic Carbon	2.37	10.11	5.42	0.19

ND= Not determined

Experimental Procedure

The experiment was a factorial in Completely Randomized Design (CRD) with two factors, namely, treatments and days of incubation. The treatments were replicated three times. The samples were incubated for eighty four days and the soil properties were determined at fourteen days intervals.

Soil Properties Determination

Soil pH was determined with the pH meter in water at a ratio of 1:2.5 soil to distilled water suspension (Thomas, 1996); exchangeable acidity was determined by the method of Mclean (1982) as outlined by Udo *et al.,* (2009) using 1M KCI as the extracting solution and titrating with 0.01M NaOH and using phenolphthalein as the indicator, organic carbon was determined by dichromate – oxidation method of Walkley and Black wet oxidation method as described by Nelson and Sommers (1982).Available phosphorus was determined by Bray 2 method of Bray and Kurtz (1945) as outlined by Anderson and Ingram (1993). Exchangeable calcium was extracted with NH_4OAC buffered at pH 7.0 (Thomas, 1982) and determined using Ethylene Diamine Tetra – Acetic (EDTA). Particle size analysis was done using the hydrometer method (Gee and Border, 1986).

Statistical Analysis

The data generated were subjected to analysis of variance (ANOVA) for factorial experiment in Completely Randomized Design (CRD) using the GENSTAT package. The means were separated using the Fisher's Least Significant difference (LSD).

3. RESULTS AND DISCUSSIONS

The pre-treatment soil analysis (Table 2) showed that the soil has a textural class of Sandy loam with a pH of 4.24 and an exchangeable acidity of 1.8cmolkg^{-1}. This pH value of 4.24 fell within the range of values that were classified by Chude *et al.,* (2012) as strongly acidic. When a soil is acidic, lots of processes in the soil are affected. Some of them include the fixation of phosphorus by aluminum to form aluminum phosphate which is a complex compound that is not available to crops for uptake. Biochemistry reactions that involve mostly bacterial such as nitrification, decomposition and some nutrients transformation are put on hold because of the deactivation of the micro-organisms in acidic conditions (Johannes *et al.,* 2009 and Gazey, 2015).

Table 2. *Pre-treatment soil analysis*

Properties	Values
Sand	690 (gkg^{-1})
Silt	120(gkg^{-1})
Clay	190(gkg^{-1})
Textural Class	Sandy loam
pH(H_20)	4.24
Exchangeable acidity (cmolkg^{-1}	1.80
Available phosphorus (mgkg^{-1})	3.50
Exchangeable calcium (cmolkg^{-1})	0.46
Organic carbon (%)	0.06

The effect of the treatment on soil pH at the weeks of the incubation is shown on Table 3. The result obtained showed that the application of lime significantly ($p<0.05$) increased the soil pH at the 2nd, 4th, 6th, 8th, 10th and 12th weeks of the incubation. These were followed by the soils that received Lime + Pm. The control had the least recorded pH values. Similar increase of soil pH when Lime was applied had been reported by Onwuka and Kanu (2012). They attributed the increase of the pH to the high calcium content of the lime; this may also be the reason for the high pH recorded in the present work (Table 1). The increased pH ranges were between 9.0- 9.9 for soils that received sole lime and 8.1-9.0 for those that received lime + Pm. These pH ranges were classified as alkaline by Rengasamy (2016). Alkalinity affects the availability of some micronutrients, example iron whose deficiency causes chlorosis in crops (Whiting *et al.,* 2015). The best pH range for most biological and chemical reactions is 6.6-7.2; this is referred to as near neutral to neutral pH (Whiting *et al*., 2015). From the results obtained, the treatments whose pH fell within that range were Ash + Pm and Biochar +Pm. Increasing the pH to neutral enhance some biochemical reactions in the soil and most nutrient availability.

Table 3. *Effect of treatment on soil pH at the weeks of incubation*

Treatment	Weeks of incubation					
	2	4	6	8	10	12
Control	4.6	4.7	4.7	4.8	4.5	4.4
Ash	5.6	7.9	7.5	7.8	7.8	7.7
Biochar	6.2	6.1	6.0	5.8	5.8	5.6
Lime	9.6	9.9	9.5	9.5	9.0	9.1
Ash + Pm	6.2	6.9	7.7	7.5	7.4	7.3
Biochar + Pm	6.3	6.6	6.7	6.4	6.4	6.1
Lime + Pm	9.0	8.8	8.8	8.6	8.3	8.1
LSD	0.72	0.23	0.45	0.47	0.14	0.32

Pm= Poultry Manure

The result presented on Table 4 is the effect of the treatment on soil exchangeable acidity. Applied Lime +Pm had significantly ($p<0.05$) lower exchangeable acidity at 2 and 6 weeks of incubation. Exchangeable acidity is made up of H^+ and Al^{3+} ions which are on soil colloids of clay and organic matter. Aluminum becomes soluble in soil solution at pH below 5.5, it interferes with root growth and function, as well as restricting plant uptake of certain nutrients, namely, Ca^{2+} and Mg^{2+} (Gazey, 2016 and Douglas, *et al*., 2016). Reducing the solubility of aluminum by increasing the pH will reduce the interference of aluminum and other acidic cations in the soil.

Table 4. *Effect of treatment on soil exchangeable acidity (comlkg^{-1}) at the weeks of incubation*

Treatment	Weeks of incubation					
	2 Weeks	4 Weeks	6 weeks	8 weeks	10 weeks	12 weeks
Control	2.32	2.25	2.27	2.17	2.17	2.43
Ash	2.19	1.54	1.58	2.18	2.21	2.57
Biochar	1.58	1.59	1.59	2.17	2.17	2.58
Lime	1.23	1.28	1.25	1.28	1.54	2.21
Ash + PM	1.58	1.42	1.44	1.42	2.25	2.53
Biochar + PM	1.53	1.44	1.44	1.44	2.17	2.59
Lime + PM	1.19	1.21	1.19	1.22	1.28	2.22
LSD	0.41	0.40	0.73	0.71	0.30	0.45

At 2 and 4 weeks of incubation (Table 5), sole lime had a positive statistically significant effect on soil exchangeable calcium. Lime +Pm increased significantly ($p<0.05$) the values of exchangeable calcium at 6 and 12 weeks of incubation. Lime +Pm and Lime gave higher exchangeable calcium values over the other treatments at 8 and 10 weeks of incubation but their values were statistically at par with each other. The reason for the increase in exchangeable calcium in the lime could be because of the amount of the calcium content of the lime (Table 1). Calcium is important in the soil because it helps to flocculate clay and organic matter and this will give rise to suitable soil porosity. Some microorganism needs calcium while it also ensures proper plant root growth when it neutralizes the soil acidity. The lime used for the study was calcium carbonate and this has the potentials of neutralizing the soil acidity of the experimental soil which has a low pH (Table 2). When calcium carbonate is added to an acidic soil in water, it dissolves, hydrolyzes (Thomas and Hargrove 1984) and form calcium hydroxide which reacts with soluble aluminum and hydrogen ions in the soil solution to give insoluble $Al(OH)_3$ and water (Ano and Ubochi (2007).

Table 5: Effect of treatment on soil exchangeable calcium (cmolkg^{-1}) at the weeks of incubation

Treatment	Weeks of incubation					
	2 Weeks	4 Weeks	6 weeks	8 weeks	10 weeks	12 weeks
Control	0.27	0.25	0.47	0.47	0.40	0.50
Ash	4.70	5.70	12.70	8.30	10.70	5.00
Biochar	5.30	6.30	9.30	7.30	5.30	5.00
Lime	17.30	19.00	11.00	12.70	12.30	6.70
Ash + Pm	6.70	6.30	14.70	17.20	11.70	5.70
Biochar + Pm	5.70	6.00	11.30	10.30	9.30	4.70
Lime + Pm	14.30	13.70	16.00	17.30	12.30	10.00
LSD	0.27	0.40	0.90	1.26	0.82	0.65

The effect of the treatments on available phosphorus at the weeks of incubation is shown on Table 6. The result showed that Biochar + Pm had significantly higher available phosphorus at 2, 6 and 8 weeks during incubation. At 4 weeks of incubation, Biochar applied alone significantly ($p<0.05$) increased the soil available phosphorus, though at 10 weeks during incubation, it gave higher values that were statistically at par with the values of Ash and Biochar +Pm. At 12 weeks of incubation both Biochar +Pm and Biochar significantly ($p<0.05$) increased the soil available phosphorus. Phosphorus in the soil is very important to plants when assimilated. It helps a plant convert other nutrients into usable building blocks with which plants grow (Rhoades, 2016). The reason why Biochar + Pm and sole Biochar increased the soil available Phosphorus may not only be because of their phosphorus content but also their pH level (Table 1). Their pH content as well as their effect on soil pH as shown on Table 3, indicated that their values where between neutral meaning that it is neither acidic nor alkaline. In acidic condition, phosphorus is not available because Aluminum fixes it (Douglas, *et al.*, 2016) while in alkaline condition calcium fixes it too to form dibasic calcium phosphate, dehydrate octocalcium phosphate and hydroxylapatite (Busman, et al., 2009)**.**That may be the reason whiles the soils that received lime had fewer amounts of phosphorus because of the high calcium content of it (Tables 1 and 5).

Table 6. *Effect of treatments on available phosphorus (mgkg^{-1}) at the weeks of incubation.*

Treatment	Weeks of incubation					
	2 Weeks	4 Weeks	6 weeks	8 weeks	10 weeks	12 weeks
Control	3.38	3.39	3.45	3.45	3.44	3.45
Ash	24.40	25.29	25.29	23.87	19.13	14.63
Biochar	23.65	29.27	25.55	22.52	20.20	19.79
Lime	16.78	11.89	9.78	5.54	5.21	5.09
Ash + PM	22.27	19.89	17.78	15.89	15.33	15.24
Biochar + PM	26.22	27.29	28.16	24.68	19.12	19.76
Lime + PM	21.67	22.60	16.73	15.87	9.78	6.00
LSD	3.21	4.02	4.34	3.56	3.00	3.12

All through the days of incubation, Biochar + Pm and Biochar significantly ($p<0.05$) increased the levels of organic carbon in the soil (Table 7). Similar result of biochar increasing the soil organic carbon was obtained by Shenbagavalli and Mahimairaja (2012). The reason for this increase could be because of its carbon content. Biochar has been reported to contain high amount of carbon (Lehmann, 2007) and at such will increase the soil organic carbon. The high carbon content may be due to its method of production. Biochar is produced by the process of pyrolysis which is the subjection of biomass to high temperature and low or limited oxygen (Brockman, 2015 and Laird, *et al.*, 2009).

Table 7. *Effect of treatment on organic carbon (%) at the weeks of incubation*

Treatment	Weeks of incubation					
	2 Weeks	4 Weeks	6 weeks	8 weeks	10 weeks	12 weeks
Control	0.03	0.09	0.06	0.06	0.06	0.05
Ash	0.22	0.24	0.27	0.26	0.26	0.26
Biochar	1.02	1.22	1.26	1.29	1.33	1.34
Lime	0.14	0.13	0.11	0.09	0.10	0.08
Ash + potash	0.34	0.46	0.47	0.38	0.35	0.32
Biochar + poultry	1.04	1.24	1.26	1.39	1.49	1.52
Lime + Poultry	0.21	0.25	0.25	0.26	0.23	0.21
LSD	0.54	0.34	0.30	0.38	0.25	0.48

The result of the mean effect of the weeks on incubation on soil pH, available phosphorus and exchangeable calcium (Fig 1) indicated that the highest significant ($p<0.05$) value of available phosphorus was recorded at two weeks of incubation. The value of 19.95 recorded at two weeks of incubation was statistically not different from the value of 19.52 obtained at the fourth week of the incubation. The highest value for the exchangeable calcium was obtained at the sixth week of incubation. At the fourth week of incubation the highest value for soil pH was gotten. The three soil properties determined increased initially reached a peak and declined as the days of the incubation increased. Similar findings were reported by Naima, *et al.;* (2015)

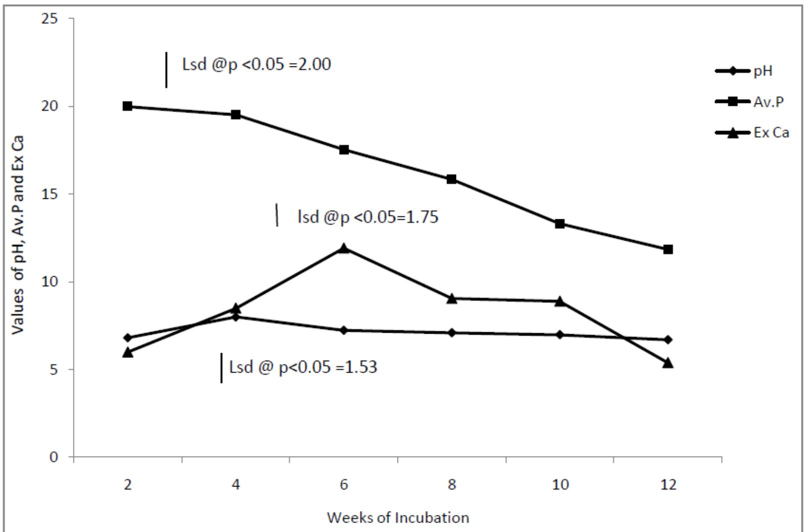

Fig 1: Mean effect of the weeks of incubation on soil pH, Avaliable P (mgkg^{-1}) and Exchangeable calcium (cmolkg^{-1}). Vertical bars denote lsd at p<0.05

At 6 and 8 weeks of incubation (Fig 2), the values of exchangeable acidity were significantly ($p<0.05$) lowest as compared to the other weeks of incubation. After the 8th week of incubation, it rose all through the period of the incubation. The highest organic carbon value was obtained at the twelfth week of the incubation. It was observed from the same Fig 2, that the graph for the soil organic carbon progressively increased from the second to the twelfth week of incubation.

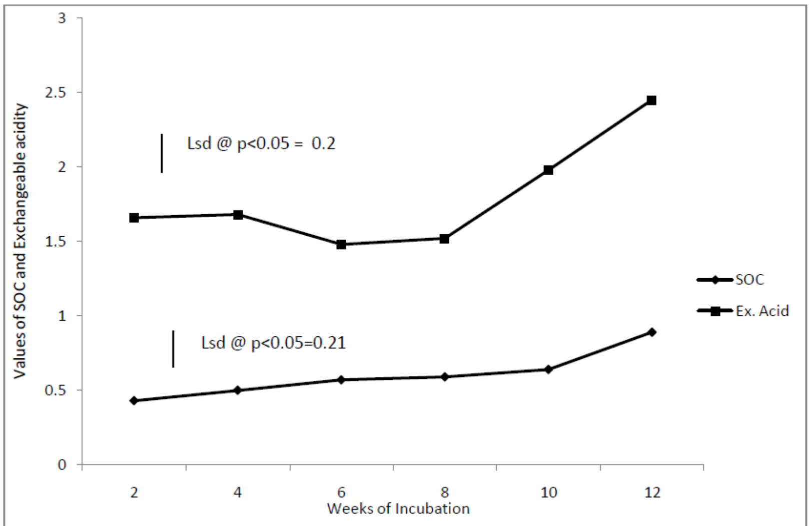

Fig 2: Mean effect of treatments on Soil Organic Carbon (%) and Exchangeable Acidity (cmolkg^{-1}) at weeks of incubation. Vertical bars denote lsd at p<0.05

The result of the Pearson correlation presented on Table 8 reveals that soil pH correlated negatively and non- significantly with exchangeable acidity and soil organic carbon. There were positive correlation but not significant among pH, exchangeable calcium as well as available phosphorus. Exchangeable acidity correlated negatively with exchangeable calcium and available phosphorus.

Table 8. *Pearson correlation of means of soil pH, exchangeable acidity, exchangeable calcium, soil organic carbon and available phosphorus.*

	pH	Ex. Acidity	Ex. Calcium	SOC	Av.P
pH	-				
Ex. Acidity	-0.4604^{ns}	-			
Ex. Calcium	0.4480^{ns}	-0.6604^{ns}	-		
SOC	-0.4519^{ns}	0.8416*	-0.3010^{ns}	-	
Av. P	0.5364^{ns}	-0.7612^{ns}	0.1902^{ns}	-0.9150**	-

*** = Significant at P < 0.001, ** = Significant at P < 0.01, * = Significant at P < 0.05, ns = Not significant

The result of the Pearson correlation presented on Table 8 reveals that soil pH correlated negatively and non- significantly with exchangeable acidity and soil organic carbon. There were positive

correlation but not significant among pH, exchangeable calcium as well as available phosphorus. Exchangeable acidity correlated negatively with exchangeable calcium and available phosphorus. No significant differences were recorded between exchangeable acidity and exchangeable calcium or exchangeable acidity and available phosphorus. Exchangeable acidity correlated positively and significantly ($p<0.05$) with soil organic carbon. Exchangeable calcium correlated negatively with soil organic carbon and positively with available phosphorus but the relationships were not significant. Soil organic carbon correlated negatively and significantly ($p<0.01$) with available phosphorus. All the soil properties that correlated negatively indicate that as they were increasing, their counterparts were decreasing. For example as soil pH was increasing, soil exchangeable acidity was decreasing. All those that correlated positively showed that as one of the soil properties was increasing, the other was also increasing. This was seen in the relationship between exchangeable calcium and available phosphorus.

4. Conclusion

Application of the amendments resulted in the mitigation of the chemically degraded soil as showed from the incubation study. Addition of amendments such as Ash, Ash + Poultry manure, Lime, Lime +Poultry manure, Biochar and Biochar + Poultry manure increased soil pH, available phosphorus, organic carbon, exchangeable calcium and reduced exchangeable acidity. The applied Biochar and Biochar + Poultry manure seems to have increased most of the soil properties; organic carbon and available phosphorus tested. They brought the pH to near neutral, which is one of the appropriate pH levels for most soil chemical and biological activities. The results obtained reveal the potentials of biochar and poultry manure in improving the soil nutrients and minerals . Further field and long term experiments are critical to substantiate the results.

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