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Case Study

Organic C Sequestration in Acid Sands Treated with Cattle-Cud Digester Under Slash-and-Burn Agriculture in Nigeria

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Abstract

The effects of fire on soil have been studied in various parts of the world, but their effect on additional or loss of carbon is not well studied in acid sands. Consequently, the heating effects on soil dynamics and C storage potentials in fallowed lands of less than five (< 5) and more than five (> 5) years were studied for three (3) eventful successive years on the soil ecosystem in Uyo, Southern Nigeria. The results revealed that land fallowed for less than five years loss 1.83 $t.C.ha^{-1}.yr^{-1}$ and the one fallowed for more than five years gain 0.03 $t.C.ha^{-1}.yr^{-1}$ during slash-and-burn. The successive burning reduces the soil bulk density by 33% in the third year the experiment lasted. Saturated hydraulic conductivity and permeability of the soil ranged between moderately slow to moderately rapid conditions. The soil acidic level in the burnt plots reduced from highly acidic (5.3) to moderately acidic (6.0). The successive increase in pH level is probably attributed to annual application of animal manure. Available phosphorus increased progressively with the increasing temperature during the first two years before it decreased. Potassium was the most limiting nutrient in the soil. Biological properties of soil were also highly affected. This is because of sensitivity of micro-organisms and invertebrates towards high temperature. Fire decreases the number and species richness of both soil dwelling. But in comparison to micro-organisms, soil dwelling invertebrates were less affected because of high mobility and burrowing habit. This research has revealed the effects of fire on the soil ecosystem. Modifications caused by fire are very striking and immediately perceptible; but the delayed changes leave their mark on the soil and determine its future evolution.

Keywords: Tillage; Fallow; Manure; Nutrients; Heat; Carbon

Practices used

Carbon sequestration; Slash-and-burn agriculture; Cattle-cud application, tillage practices.

Description of the case study

Organic carbon sequestration is the transfer of atmosphere CO_2 into soil organic matter (SOM), with longer mean residence time (MRT), so that it is not re-emitted into the atmosphere in the near future. Slash-and-burn agriculture has been in use to sequester CO_2 for decades by over 80% peasant farmers in Southern Nigeria. Depending on fallow length, the soil and vegetation are given adequate time to regenerate after a period of cropping. Stubble burning helps to reduce weed and pest infestation and ash deposited increases soil pH and fertility. However, stubble burning is known to contribute to soil structural degradation. Slash-and-burn agriculture is not sufficiently understood and quantified in areas like Southern Nigeria with high rainfall intensities (3000 - 4000 $mmyr^{-1}$). Field experiment was carried out during 2010 - 2012 in an area measuring $864.8m^2$ on a slope of 9%. Twenty-four experimental plots, each measuring $12 \times 3m^2$, separated from one another by 20 cm fireproof tracts were laid out. Experimental fire was performed with measured dry biomass of 50, 100, and 150 kg m^{-2} that produced three levels of heat intensities. Weather conditions were mild with relative humility of 50 - 59% and variable winds speed up to 7 km h^{-1}. This resulted in a slow creeping ground fire with 2.5 m average flame heights. Maximum temperatures during the burning were recorded with fire resistance soil thermometer, while gas fluxes were measured with portable sensitive gas dictators. Thereafter, sweet potato was planted as test crop and the soils were amended with cattle-cud digester a week after planting. Composite soil samples were taken for analyses at the end of the cropping cycle. The effects of slash-and-burn on carbon sequestration and changes in soil properties at different heating intensities and the potential of animal manure in correcting the depleted soil quality attributes due to fire temperatures and crop yields were reported.

Context of the case study

The research was conducted in continuous cropped acid sandsarable experimental plots, located at the University of Uyo Teaching and Research Farm (UUTRF), Use-Offot, and Ikpa Road, Uyo. Uyo is in Southern Nigeria, located between latitudes 4º 30' and 50 3'N and longitudes 7º 31' and 8º 20' E and altitude 65m from the sea level. The area is divided into two distinct seasons, the wet and dry seasons. The wet or rainy season begins from April and lasts till October. It is characterized by heavy rainfall of about 2500 - 4000 mm per annum.

Possibility of scaling up

This research could be implemented both in rainfed and irrigated crops growing agriculture worldwide.

Potential of c sequestration/potential of additional storage

Locations	Climate zone	Soil type	Baseline C stock (t C.ha^{-1})	Additional/Loss of C storage potential (t C.ha^{-1}.yr^{-1})	Duration	More information	Reference
University of Uyo (Town Campus, Fallowed for < 5 yrs.) Use Offot Southern Nigeria	Humid tropic	Ultisol: low pH, dominatedby kaolinite and low activity clay fraction	35.66	1.83 (Loss of C)	3 years	Shifting from bush fallowing to traditional tillage at 15 cm depth	Unpublished
University of Uyo (Annex Campus, Fallowed For > 5 yrs.) Uyo, Southern Nigeria	Humid tropic	Ultisol: low pH, dominated by kaolinite and low activity clay fraction	32.29	0.03 (Gain)	3 year	Shifting from bush fallowing to traditional tillage at 15 cm depth	Unpublished

Other benefits of the practice

Benefits on soil properties

Fire is a powerful and rapidly acting modifier of the soil environment. Sudden modifications are very striking and immediately perceptible; but the delayed changes leave their mark on the soil and determine its future evolution. Therefore, in order to understand the effects of the impact of fire on the ecosystem, it was important to follow three (3) years eventful successive effects of the fire on the soil ecosystem in Southern Nigeria. Soil properties after slash-and-burning a fallowed land of less and more than 5 years in Uyo, Nigeria are shown in table 1-6.

Physical properties

The soil surface was heated, killing weed seeds and initially improving soil structure. Although the plots were reasonably uniform in regards to physico-chemical parameters at the time of the performance of experimental fires, they did have highly variable moisture conductivity, permeability, bulk density and porosity (Table 1).

In the area whose fallow period was less than 5 (Use Offot), data reported in table 1 show that, increase in burning temperature causes an annual decrease in the soil bulk density and increase in total porosity of upto 23% in tilled plots amended with 30 t ha^{-1}

of cattle-cud digester (animal manure). Whereas bulk density and porosity had no clear graphic pattern in untilled plots, but generally reduces as the maximum heat intensity increases. In the area with more than 5 years fallow period (Uniuyo Annex campus), the same trend of soil bulk density subsisted. The successive burning reduces the soil bulk density by 33% in the third year the experiment lasted. Saturated hydraulic conductivity and permeability of the soil ranged between moderately slow to moderately rapid conditions. No clear graphic correlation was found between increase in the soils' permeability and the soil temperatures during the biomass burning. Rather, animal manure was seen to structurally maintaining the stability of this burnt acid sand and increases its readiness of fluids transmission.

			Year 2010				Year 2011				Year 2012			
Locations	**Bio-mass burned (kg m-^{2})**	**Max Soil Temp. ^{0}C**	**BD g cm^{-1}**	**f %**	**K_{sat} cm hr^{-1}**	**M_{sat} (×10-^{1}) cm hr^{-1}**	**BD g cm^{-1}**	**f %**	**K_{sat} cm hr^{-1}**	**M_{sat} (×10-^{1}) cm hr^{-1}**	**BD g cm^{-1}**	**f %**	**K_{sat} cm hr^{-1}**	**M_{sat} (×10-^{1}) cm hr^{-1}**
*University of Uyo (Town Campus) Use Offot		**Tilled plots after slash-and-burn**												
	0	24.3	1.47	44.53	0.44	3.31	1.29	51.32	14.36	1.08	1.22	53.96	5.74	0.75
	50	35.6	1.37	48.30	0.39	7.26	1.12	57.74	37.91	3.75	1.31	50.57	4.79	3.75
	100	47.8	1.55	41.51	0.54	6.25	1.03	61.13	60.31	19.62	0.93	64.91	22.02	8.25
	150	60.4	1.36	48.68	0.54	6.18	0.96	63.77	70.85	8.25	0.85	67.92	38.29	19.62
	Mean		1.44	45.76	0.48	5.75	1.10	58.49	45.86	8.18	1.08	59.34	17.71	8.09
		Untilled plots after slash-and-burn												
	0	24.3	1.26	52.45	0.26	0.75	1.25	52.83	0.750	0.082	1.48	44.15	1.010	0.015
	50	35.6	1.17	55.85	0.22	1.01	1.26	52.45	1.010	0.087	1.38	47.92	0.011	0.094
	100	47.8	1.12	57.74	0.28	0.011	1.08	59.25	0.011	0.002	1.42	46.42	0.342	0.011
	150	60.4	0.98	63.02	0.29	0.34	0.78	70.57	0.343	0.019	1.22	53.96	0.806	0.017
	Mean		1.13	57.265	0.26	0.53	1.093	58.77	0.528	0.051	1.375	48.11	0.542	0.034
**University of Uyo (Annex) Uyo		**Tilled plots after slash-and-burn**												
	0	32.5	1.68	36.60	0.42	2.70	1.35	49.06	8.04	8.67	0.88	66.79	13.4	2.12
	50	67.9	1.45	45.28	0.46	8.00	1.26	52.45	11.49	2.12	1.07	59.62	30.64	3.17
	100	85.4	1.43	46.04	0.47	9.84	1.28	51.70	21.06	6.85	1.06	75.85	53.7	6.85
	150	93.4	1.52	42.64	0.66	6.57	1.22	53.96	29.49	3.17	1.02	61.51	78.5	8.67
	Mean		1.52	42.64	0.50	6.78	1.28	51.79	17.52	5.20	1.01	65.94	44.06	5.20
		Untilled plots after slash-and-burn												
	0	32.5	1.31	50.57	0.33	0.806	1.24	53.21	0.0202	0.049	1.64	38.11	0.151	0.049
	50	67.9	1.24	53.21	0.19	0.855	0.97	63.40	0.1830	0.001	1.52	42.64	0.919	0.021
	100	85.4	1.18	55.47	0.29	0.020	1.11	58.11	0.8060	0.056	1.27	52.08	0.108	0.031
	150	93.4	1.28	51.70	0.31	0.183	1.17	55.85	0.8553	0.021	1.34	49.43	1.648	0.029
	Mean		1.25	52.738	0.280	0.466	1.123	57.64	0.466	0.031	1.44	45.56	0.707	0.033

*= land fallowed for < 5 years before slash and burn, ** = land fallowed for > 5 years before slash and burn, f= porosity, Ksat = hydraulic conductivity, Msat = permeability, BD = bulk density

Table 1*:* Effects of slash and burn and tillage on physical and hydrological properties of acid soil treated with animal manure (30 t ha^{-1}).

At Use Offot area as shown in table 2, the dominant stable aggregate in the tilled plots treated with 30 t ha^{-1} of animal manure after slash-and-burn was 4 mm (3.73) aggregate size. Whereas the aggregates size that appeared more pronouncedly destabilized during the burning exercise was 0.25 mm (0.13) aggregate size. In the untilled plots, dominant stable aggregate sizes to water after slash and burn were 1.00 (25.58) and 0.5 mm (24.73) aggregates. Whereas the most unstable aggregates to water after burning experiment was 4 mm (2.51) with heating temperature of 60.4^0C causing 100% destability. It is worthy of note that aggregate size greater than 4 mm from a fallowed land (< 5 years) hardly withstood heat above 60^0C during experimental burning under untilled condition even when amended with animal manure. But in a situation where the land was fallowed for more than 5 years, increase in soil temperature upto 85^0C during burning increases 4 mm aggregate size mostly in tiled plot. In fallowed land of more than 5 years before slashing and burning, 4 mm aggregate (4.99) was the dominant aggregate size stable to water, followed by 0.25 mm (3.81) in the tilled plots. But in an untilled condition, 0.5 mm (35.25) was most resistance to deformation action of water, followed by 1.00 mm (25.68). On the whole, the Mean Weight Diameter (MWD) of the untilled plots was significantly more structurally stable than tilled plots after slash and burn exercise.

			Wet sieving aggregate sizes (mm) in Tilled plots after slash-and-burn						Wet sieving aggregate sizes (mm) in Untilled plots after slash-and-burn					
Locations	**Biomass burned (kg m^{-2})**	**Maximum soil Tempt. ^{0}C**	**4**	**2**	**1**	**0.5**	**0.25**	**MWD**	**4**	**2**	**1**	**0.5**	**0.25**	**MWD**
University of Uyo (Town Campus)	0	24.3	2.90	0.60	0.80	0.70	0.10	0.09	3.00	17.58	25.00	36.83	0.67	0.08
	50	35.6	3.50	0.40	0.70	0.30	0.20	0.18	3.83	18.00	25.83	31.83	0.69	0.27
Use Offot	100	47.8	4.00	0.30	0.50	0.50	0.10	0.11	3.20	3.51	23.00	2.77	0.07	0.18
	150	60.4	4.50	0.60	0.90	0.60	0.10	0.11	0.00	12.00	28.50	27.50	0.49	0.20
	Mean		3.73	0.48	0.73	0.53	0.13	0.12	2.51	12.77	25.58	24.73	0.48	0.18
University of Uyo (Annex)	0	32.5	2.32	2.21	1.53	0.20	3.20	0.22	3.00	17.58	25.00	36.83	0.67	0.27
	50	67.9	4.51	3.0	1.52	0.32	1.33	0.52	4.00	21.33	26.50	33.50	0.77	0.86
Uyo	100	85.4	7.21	3.22	1.41	0.32	4.61	0.24	3.50	19.67	26.33	37.50	0.71	0.36
	150	93.4	5.91	3.34	1.24	0.35	6.11	0.32	3.50	19.67	24.67	33.33	0.72	0.36
	Mean		4.99	2.94	1.43	0.30	3.81	0.33	3.50	19.56	25.63	35.29	0.72	0.46

Table 2: Effects of slash and burn and traditional tillage system on aggregate stability of acid soil treated with animal manure (30 t ha-1) (from 2010 -2012).

Chemical properties

Large quantities of nutrient ions were spread in the ash. The amount of ash was much when 150 kg m^{-2} was burned compared 50 and 100 kg m^{-2}. Soil pH (Table 3) increased with increasing temperature. This was probably due to increasing of the buffer action from the ash associated concomitantly with combustion of biomass. The soil acidic level in the burnt plots reduced from highly acidic (5.3) to moderately acidic (6.0). The successive increase in pH level is probably attributed to annual application of animal manure. Available phosphorus increased progressively with the increasing temperature during the first two years before it decreased. Potassium was the most limiting nutrient in the soil. At all treatments, K followed a sigmoid curve trend with slight increase at temperature above 47^0C. Calcium at Use Offot showed a slight increase in the second year of practice, but progressively increased at least 75% and 17.6% in tilled and untilled plots respectively at Annex campus in the successive year. Magnesium increased as the soil maximum temperature increased. The complete combustion of the biomass is responsible for the abundant Mg is the soil which is not completely used up by the plant within the growing cycle. Significant portion of the nutrient is apparently loss through erosion. As shown in table 4, Rain Water Used Efficiency (RWUE) remained consistently high with increased in soil temperature in both tillage practices. At 60^0C maximum soil temperature, an average of 2.23 RWUE was recorded in plot that was under 5 years fallow period. Whereas, 93^0C maximum soil temperature created 4.25 RWUE in plots fallowed for more than 5 years before slash-and-burn agriculture.

			Year 2010					Year 2011					Year 2012				
Locations	Biomass burned (kg m-2)	Max Soil Tempt. 0C	pH	P	K	Ca^{2+}	Mg^{2+}	pH	P	K	Ca^{2+}	Mg^{2+}	pH	P	K	Ca^{2+}	Mg^{2+}
University of Uyo (Town Campus) Use Offot		**Tilled plots after slash-and-burn**															
	0	24.3	5.5	23.8	0.1	4.1	1.5	5.3	95.4	0.04	2.04	1.60	5.1	0.68	0.86	1.40	0.99
	50	35.6	5.7	17.5	0.1	3.4	1.6	6.6	93.6	0.05	3.56	1.63	6.3	0.87	0.85	1.89	1.40
	100	47.8	5.8	21.5	0.1	3.5	1.9	6.8	99.8	0.08	3.55	1.61	6.4	0.73	0.84	1.73	1.28
	150	60.4	6.6	22.9	1.2	3.6	1.8	6.5	113.5	1.0	4.48	1.74	6.2	1.07	0.86	1.85	1.19
	Mean		5.9	21.4	0.4	3.7	1.7	6.3	100.5	0.29	3.41	1.65	6.0	0.84	0.85	1.72	1.22
		Untilled plots after slash-and-burn															
	0	24.3	5.2	24.5	0.8	1.4	0.9	5.5	82.9	0.04	2.65	1.52	5.1	1.08	0.95	2.90	1.57
	50	35.6	5.4	28.0	1.4	1.9	1.3	6.4	91.4	0.06	4.00	1.60	6.3	1.72	0.85	2.01	1.48
	100	47.8	5.5	37.3	1.3	1.7	1.4	6.2	94.3	0.09	4.44	1.58	6.1	1.59	0.94	2.44	1.28
	150	60.4	5.5	37.9	1.5	1.9	1.3	6.9	133.6	1.01	4.89	1.75	6.4	1.19	0.93	1.91	1.47
	Mean		5.40	31.9	1.3	1.7	1.2	6.3	100.6	0.30	4.00	1.61	6.0	1.40	0.92	2.3	1.45
University of Uyo (Annex) Uyo		**Tilled plots after slash-and-burn**															
	0	32.5	5.3	20.1	0.8	1.4	0.7	5.1	82.4	0.05	3.00	1.50	5.3	42.97	0.11	10.24	2.62
	50	67.9	5.6	45.2	1.0	2.1	1.18	6.7	93.5	0.08	3.52	1.58	6.5	45.02	0.11	10.48	2.55
	100	85.4	5.6	70.3	1.0	2.5	1.28	6.4	99.7	0.08	4.48	1.82	6.6	48.69	0.11	10.46	2.62
	150	93.4	5.8	89.7	1.2	2.9	1.78	6.8	123.6	1.00	4.47	1.96	6.5	42.75	0.11	9.94	2.59
	Mean		5.6	56.3	1.0	2.2	1.2	6.3	99.8	0.30	3.87	1.72	6.3	44.86	0.11	10.28	2.60
		Untilled plots after slash-and-burn															
	0	32.5	5.2	18.9	0.8	1.6	0.9	5.3	84.5	0.06	3.04	1.43	5.3	62.77	0.1	9.76	2.62
	50	67.9	5.6	37.9	0.9	3.7	1.6	6.6	97.8	0.08	3.64	1.64	6.5	55.6	0.11	9.04	2.57
	100	85.4	5.8	68	1	3.9	1.5	6.8	94.7	0.1	4.47	1.66	6.5	75.21	0.11	10.35	2.83
	150	93.4	6	73.1	1.5	4.5	1.8	6.7	99.9	1.1	4.89	1.7	6.4	62.67	0.12	10.2	2.73
	Mean		5.7	49.5	1.1	3.4	1.5	6.4	94.2	0.34	4.01	1.61	6.2	64.1	0.11	9.84	2.69

Table 3: Effects of slash and burn and traditional tillage on Acidity and macronutrients of acid soil treated with animal manure (30 t ha^{-1}).

Biological properties

Soil arthropods extracted from the soil samples at 5 and 10 cm depths were examined and identified under a dissecting microscope (Comecta Trinocular Stereomicroscope e Model SQF-E). Five classes of arthropods; Acarina, Insecta, Diplopoda, Chilopoda, and Aranaee, were isolated from the soil samples (Table 8). Mean Acarina density before vegetation burning ranged from nil to 88 individuals m^{-2} soil area and from nil to 35.5 individuals m^{-2} soil area after slash and burn exercise. Interestingly, *Archoplophora rostralis* (Willmann) increased above 74% after burning and none of *Gamasina* sp and *Eutrachyes* sp. survived the heat from burning. While Insecta population density varied from nil to 46 individuals m^{-2} and nil to more than an individual m^{-2} before and after burning respectively. Families of Insecta reduced from nil to 98%, except for the families of *Tenebrionidae Curclionidae*, and Termitidae. The classes Chilopoda, and Aranaea were only found in the burnt plots. A mean total of 164.5 and 96 individuals arthropods m^{-2} were isolated from the un-burnt and burnt soils respectively. More than 88% of the arthropods were either destroyed or burrowed beyond 10 cm depths during the burning. Heat resulting from burning 50, 100 and 150 Kg m^{-2} biomass affected 60, 98, and 70% of the arthropods respectively at 5 cm depth, whereas at 10 cm depth, the differences were 45, 60 and < 1% respectively across the field (Figure 1).

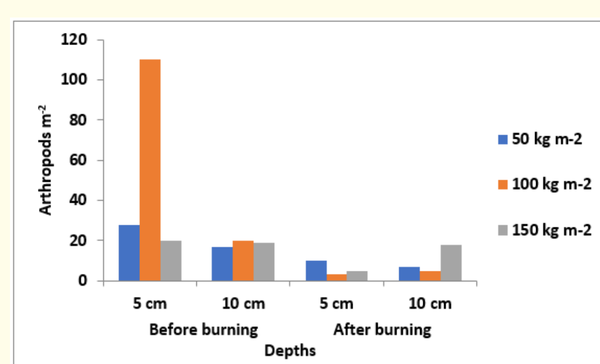

Figure 1: Mean arthropod density (individual m-2) at three levels of burnt biomass on surface soil.

Locations	Biomass burned (kg m^{-2})	Maxi-mum soil Tempt. ^{0}C	RWUE	Tuber Girth cm	Tuber Length cm	No of Tuber per plot	Yield (t ha^{-1})	RWUE	Tuber Girth cm	Tuber Length cm	No of Tuber per plot	Yield (t ha^{-1})
			Tilled plots after slash-and-burn					Untilled plots after slash-and-burn				
University of Uyo (Town Campus) Use Offot	0	24.3	1.51	13.91	12.51	28.50	12.76	0.99	12.16	18.32	14.08	10.95
	50	35.6	1.71	15.41	17.59	31.33	15.33	1.59	16.09	16.06	15.77	14.68
	100	47.8	1.99	16.9	18.32	42.67	8.52	1.73	16.44	18.76	19.20	12.30
	150	60.4	2.23	14.74	16.06	60.50	22.43	2.99	15.57	21.07	23.81	14.06
	Mean		1.86	15.24	16.12	40.75	14.76	1.83	15.07	18.55	18.22	13.00
University of Uyo (Annex) Uyo	0	32.5	1.35	3.19	5.92	23.08	9.65	1.95	13.61	15.67	26.33	12.16
	50	67.9	3.19	16.99	18.76	52.58	20.54	2.18	15.40	21.33	42.67	16.09
	100	85.4	3.38	19	21.07	56.83	17.13	2.95	17.65	23.30	32.33	16.44
	150	93.4	4.25	18.83	26.08	61.33	21.22	3.59	20.04	28.42	60.5	15.57
	Mean		3.61	13.06	15.25	48.46	17.13	2.67	16.67	22.18	33.78	15.07

Table 4: Effects of heating temperatures and tillage on rain water use efficiency, yield and yield parameters of sweet potato in acid soil treated with animal manure (30 t ha-1).

RWUE: Rainwater Use Efficiency.

On minimizing soil threats

Minimizing/Preventing soil threats	Yes/No/NA	Explanation/Related soil property
Soil erosion/soil losses	Yes	The application of animal manure in tiled plots under slash and burn agriculture increased the infiltration of the soil. Manure amendment significantly (P < 0.01) decreased bulk density and consequently increased total porosity [1]. Increase in soil water storage.
Foster nutrient balance and cycles (N,P,K)	Yes	Manure increases and maintains soil fertility by providing N, P, K, S, Ca, Mg, Na and other trace elements such as Fe, Mn, Cu, Zn [2]. Increases soil organic matter content and cation exchange capacity.
Soil salinization and alkalinization	NA	
Soil contamination/pollution	NA	
Soil acidification	Yes	Ash associated with burning concomitantly increasing of the buffering action of the soil. It also improves the pH of acid and calcareous soils [2]
Soil biodiversity loss	Yes	Slashed and burned areas experienced strong negative impact on biodiversity specifically on immobile, small species [3]. However, these effects could be balanced if the soil is amended with animal manure from where re-colonization can re-establish species destroyed in the burning and cropping phases.
Soil sealing	Yes	Soil sealing decreased exponentially from the burned phase [4] to the early stage of plant growth where the leaves intercept the kinetic energy of the rain drop impacts that causes soil sealing. In general, areas undergoing slash and burn with animal manure amendment are stable and the fallow length, as well.
Soil compaction	Yes	Cattle manure amendments in slashed and burned soils decreased bulk density and increased hydraulic saturation of the soil. it may also temporarily improve soil aggregation.
Soil water management	No	Ash deposits in the pore spaces likely accounted for 0.8 and 3% reduction in available water capacity [5].

On potato production (Tuber girth, tuber length, number of tuber and yield)

According to data in table 4, in < 5 years fallow condition, maximum soil temperature of 47.8^{0}C gave the highest tuber girth of 16.9 cm and 16.44 cm in tilled and untilled plots, respectively. Also, this temperature produced the longest potato tuber length (18.32 cm). Whereas the highest tuber number (60.50) and the highest tuber yield of 22.43 t ha^{-1} in tilled plots were produced at maximum soil 60.4^{0}C. But in untilled plots, 60.4^{0}C maximum soil temperature produced the longest tuber (21.07 cm) and the highest number tubers per plot (23.81), when 35.6^{0}C soil temperature gave the highest tuber yield (14.68 t ha^{-1}).

The experiment carried out in the fallowed area > 5 years showed that, maximum soil temperature of 93.4^{0}C generated from 150 kg m^{-2} of burnt biomass in the tilled plots produced the longest tuber (26.08 cm), the highest number of potato tuber (61.33) per plot and yield (21.22 t ha^{-1}). On the other hand, in the untilled plots, 93.4^{0}C maximum soil temperature produced the largest tuber girth (20.04 cm), longest tuber length (28.42 cm) and the highest numbers of potatoe tuber per plot. Surprisingly, the average tuber yield per hectare dropped from 16.44 to 15.57 t ha^{-1} when the soil temperature due to burning increased from 85.4^{0}C to 93.4^{0}C in the untilled plots.

On C sequestration and N storage

As shown in table 5, the two fallow periods received the same biomass treatment, but the heating temperatures after slash and burn varied from 24.5 - 60.4^{0}C and 32.5 - 93.4^{0}C between plots that were fallowed for < 5 years and > 5 years, respectively. The general sequestrations trend revealed that carbon and nitrogen storages increased annually in tilled plots, but did not correspond with the heat intensity of the burnt biomass. The baseline C and N stocks varied significantly between fallow periods and tillage practices (Table 7). In locations where fallow period was less than 5 years, 4.7 t C. ha^{-1} and 0.148 t N. ha^{-1}were stored in tilled plots. Whereas 8.36 t C. ha^{-1} and 0.209 t N. ha^{-1} were loss in the untilled plots after the experiment. But in the land area that was fallowed for more than 5 years before slashed and burnt, the amount of carbon stored was 0.23 t C. ha^{-1}, whereas, nitrogen stock averaged 0.006 t N. ha^{-1} in the tilled plots. Whereas in the untilled plots, 0.16 t C. ha^{-1} of C was loss due to slash and burn. Interestingly, judging from the antecedent N stock, there was no change in N storage in the untilled plots after the experimental fire and application of animal manure.

			C sequestration			Nitrogen Storage		
Locations	**Biomass burned (kg m^{-2})**	**Max Soil Tempt. ^{0}C**	**2010**	**2011**	**2012**	**2010**	**2011**	**2012**
			Tilled plots after slash-and-burn					
University of Uyo (Town Campus)	0	24.3	7.11	9.96	10.22	0.178	0.249	0.256
	50	35.6	8.95	10.17	10.98	0.224	0.254	0.274
Use Offot	100	47.8	7.88	11.46	13.61	0.197	0.287	0.340
	150	60.4	8.94	10.34	13.63	0.223	0.258	0.341
	Mean		8.22	10.48	12.11	0.205	0.262	0.303
			Untilled plots after slash-and-burn					
	0	24.3	9.91	9.05	25.07	0.248	0.226	0.627
	50	35.6	8.59	9.12	24.55	0.215	0.228	0.614
	100	47.8	8.63	6.42	18.03	0.216	0.161	0.451
	150	60.4	9.02	4.01	18.65	0.226	0.100	0.466
	Mean		9.04	7.15	21.58	0.226	0.179	0.539
			Tilled plots after slash-and-burn					
University of Uyo (Annex)	0	32.5	9.93	9.68	10.31	0.275	0.264	0.327
	50	67.9	9.14	8.10	11.56	0.231	0.276	0.461
Uyo	100	85.4	7.54	8.81	11.23	0.243	0.316	0.207

	150	93.4	10.49	8.93	13.48	0.286	0.382	0.213
	Mean		9.28	8.88	11.65	0.259	0.309	0.302
			Untilled plots after slash-and-burn					
	0	32.5	11.0	10.56	13.10	0.248	0.242	0.258
	50	67.9	9.25	11.02	18.43	0.228	0.203	0.289
	100	85.4	9.73	12.65	8.28	0.188	0.220	0.281
	150	93.4	11.5	15.29	8.52	0.262	0.223	0.337
	Mean		10.37	12.38	12.08	0.232	0.222	0.291

Table 5: Effects of heating temperatures and traditional tillage on C and N stocks (t ha^{-1}) in acid soil treated with animal manure (30 t ha^{-1}).

Climate change mitigation and adoption

As indicated in table 6, the measurable gases emitted during experimental fire at different heat concentrations varied significantly. The values for these gases were above the permissive limits (especially, CO 10 mg m^{-2}) indicating air pollution through these activities. Therefore, despite the merits of quick release of occluded nutrients during burning, heating temperatures with the attendant smoke during slash-and-burn exercise of land clearing altered soil properties and air quality. These alterations have bearing on the sustainability of nutrients in the soil, also when the emitted gases (SO_2 and H_2S) reacts with water vapour in the atmosphere, it results in acid rain formation that increased soil acidity. Edem., *et al.* [6] demonstrated the catalytic destruction of ozone by nitric oxide emitted from bush burning. This is one of the aspects that agriculture contributed in global warming when highly reactive mono-molecular oxygen is struck by ultra violet light and the prevented dangerous UV light rays reaches the earth surface. Generally, regardless of the quantity of biomass per square meter soil, CO was the most emitted gas while SO_2 was least emitted during the burning exercise. Soils in Uyo, Southern Nigeria exhibit marked differences in physical characteristics under slash and burn land use. These significant changes in soil properties in the upper 15 cm layer in the burnt plot increased the rate of soil disturbances which in turn affects the future and sustainable of crop production.

			2010					2011					2012				
Locations	**Biomass burned (kg m-2)**	**Max Soil Tempt. 0C**	**NO_2**	**SO_2**	**CO**	**H_2S**	**Cl_2**	**NO_2**	**SO_2**	**CO**	**H_2S**	**Cl_2**	**NO_2**	**SO_2**	**CO**	**H_2S**	**Cl_2**
University of Uyo (Town Campus)	50	35.6	0.33	ND	14.6	0.46	0.48	0.33	ND	24.2	0.2	0.47	0.24	ND	19.8	0.4	0.24
	100	47.8	0.36	0.1	26.9	0.56	0.88	10.8	0.1	26.1	0.35	0.42	0.42	ND	24.8	0.37	0.69
	150	60.4	0.57	0.2	32.9	0.58	0.75	17.1	0.2	20.6	0.69	0.98	0.42	0.3	28.0	0.99	0.52
Use Offot	Mean		0.42	0.15	24.8	0.53	0.70	9.41	0.15	23.6	0.41	0.62	0.36	0.30	24.2	0.59	0.48
University of Uyo (Annex)	50	67.9	0.18	ND	10.7	0.5	0.6	5.4	ND	15.3	0.27	0.34	0.24	ND	10.2	0.24	0.27
	100	85.4	0.60	0.1	13.2	0.7	0.83	18	0.1	20.4	0.5	0.7	0.31	0.2	23.4	0.69	0.56
	150	93.4	0.54	0.1	15.7	1.47	0.79	16.2	0.2	21.2	0.7	0.86	0.36	0.3	24.8	0.72	0.87
Uyo	Mean		0.44	0.10	13.2	0.89	0.74	13.20	0.15	18.97	0.49	0.63	0.30	0.25	19.5	0.55	0.57

Table 6: Emission of gases (mg m^{-2}) during experimental fire passage on arable land at different heating intensities.

Locations	Treatments	Baseline C stock (t C.ha^{-1})	C storage	Differences	Baseline N stock (t N.ha^{-1})	N storage	Differences
University of Uyo (Town Campus)	Tilled plots	27.29	31.99	4.7	0.682	0.800	0.148
Use Offot	Untilled plots	44.03	35.67	-8.36	1.101	0.892	-0.209
University of Uyo (Annex)	Tilled plots	34.66	34.89	0.23	0.866	0.872	0.006
Uyo	Untilled plots	29.92	29.76	-0.16	0.748	0.748	0

Table 7: Effects of animal manure (30 t ha^{-1}) on C and N storages in acid sands under traditional tillage system of farming after slash-and-burn method of land clearing.

		Soil Fauna population		
Class	**Soil fauna**	**Before burning**	**After burning**	**Mean total**
Acarina	*Archoplophora rostralis* (Willmann)	9	35.5	44.5
	Gamasina sp	17	-	17.0
	Eutrachyes sp	3	-	3.0
	Peloribates nigeriensis (Badejo)	5	0.5	5.5
	Nothrus ifaensis (Badejo)	-	2.0	2.0
	Nothrus insavatus (Badejo)	3	0.5	3.5
	Mulierculia inexpectata (Badejo)	88	1.0	89.0
Insecta	Cantharidae	46	1.0	47.0
	Chrysomelidae	15	1.0	16.0
	Carabidae	19	0.5	19.5
	Cleridae	3	-	3.0
	Tenebrionadae	-	1.5	1.5
	Curclionidae	-	1.0	1.0
	Termitidae	-	1.5	1.5
Diplopoda		1	-	0.5
Chilopoda		-	0.5	1.0
Aranae		-	1.0	4.0
	Immature arthropods	4	-	

Table 8: Soil fauna classes (individual m^{-2}) distribution in plots before and after experimental burning.

Socio-economic benefits

Slash and burn method of agriculture is the traditional [7] system of land clearing in Southern Nigeria. This method according to Babalola [8] has been an integral part of land cultivation and widely practiced by over 90% of farmers in South eastern Nigeria. Burning aid in clearing bush debris and reduction of weed infestation that would have been competing with crops for sunlight, water and soil nutrients as reported by Babalola (2000). The ash deposits after burning increased the pH of the soil and help to fertilize the soil. This is done by immediate release of the mineral nutrients like Mg, Ca and Available P, for crop use. Brye [9] reported that increased soil temperature after burning, stimulate biological activities, and increase organic matter mineralization to enhance nutrient availability with increase susceptibility of the soil to erosion. Furthermore, stubble burning had been identified as a contributor to soil structural degradation and loss of plant nutrients. Contrary to this, with amendment of animal manure after burning, these studies have suggested that burning activities might increase availability of plant nutrients and also reported that charcoal residues and charred biomass left on kiln sites improve the fertility of tropical soils by direct nutrient addition and retention. These effects have been sufficiently quantified in this area with very high rainfall intensity that evidenced in high leaching and erosion associated with slope. Good crop yields and C sequestration are normally obtained in the first two years after slash-and-burn farming system, but declined thereafter. The suitability of land for slash-and-burn agriculture depends partly on its sensitivity to erosion.

Tradeoffs or conflicts with other practices

Tradeoffs with other soil threat

Stubble burning has affected a variety of soil properties including the loss or reduction of structure and soil organic matter and reduced porosity. These changes also resulted in various indirect impacts including increased hydrophobicity (water repellency) which results in decreased infiltration and increased run-off which often results in increased erosion. Although, Alegre and Cassel [10] has suggested that the best possible system for removing stubble materials was still that of burning. In regard to nutrient cycling, burning releases to the soil about half of the nitrogen and phosphorus of the burning biomass and practically all of the other nutrients in the form of ash, which also causes a liming effect. Higher soil temperature following burning also accelerates the decomposition of soil organic matter. These factors provide high nutrient availability for one or two years to grow food crops, depending on the inherent fertility status of the soil [11]. Farmers that aim at benefiting from the lush re-growth after burning tend to subject their grassland to fire every season, irrespective of the amount of moribund herbage at the end of the season, thus exposing the surface mat layer to destruction [12]. It is also believed to rid the grassland of parasitic insects and to prevent the encroachment of undesirable invasive plant species. The later is subjective since fire is also known to break seed dormancy in some of the common invasive species [13]. Agricultural burning had been also identified as a contributor to soil structural degradation [14] and loss of plant nutrients. Agricultural burning has a detrimental effect on the environment and health of mankind. All fires, regardless of whether they are natural or manmade, alter the re-cycling of nutrients, the biotic, physical, moisture, and temperature characteristics of soil [15]. The extent of fire effects on soil physical properties vary considerably depending on fire intensity, fire severity, and fire frequency. Its intensity is the factor that determines the soil status with respect to its response to nutrient losses which affect crop production. Studies have shown that severe burning has drastic effects on soil texture, color, mineralogy, and other soil properties [16]. A significant decrease in clay fraction and a corresponding increase in sand fraction of severely burnt soils may eventually lead to poor water- holding capacity [17]. Low to medium fire severity resulted in darkening of the topsoil while high-severity burns (> 600°C) caused pronounced reddening of the topsoil, accompanied by an increase in both munsell value and chroma [18]. Moreover, majority of farmers in Akwa Ibom State, Nigeria practiced slash and burned method of land preparation without animal manure application. This practice is impinging on the structural stability of soils.

Possible GHG emissions

As summarized in table 6, the measurable gases (mg m^{-2}) emitted during experimental fire were NO_2, SO_2, CO, H_2S, and Cl_2. The flux of CO emitted from the burning exercise was significantly higher (24.8, 23.6, 24.2) in the location that was fallowed for < 5 years than (13.2, 18.97, 19.5) that fallowed for more than 5 years. The respective volume of gases emitted varied considerably, regardless of the quantity of biomass and heating intensity, and increased successively as the practice progresses. Also, Slash-and-burn agriculture alone contributes significantly about 20% to the annual increase in radiation [19] forcing GHGs to trap heat relative to carbon dioxide (CO_2) through emissions of NO_2, SO_2, CO, H_2S and Cl_2 to a large extent.

Conflict with other practices

Slash and burn system of agriculture amended with cattle manure is often compared to amendment with chemical fertilizers in terms of quantity of nutrients they contain. In such comparisons, it is inferior to chemicals; animal manures are not concentrated sources of nutrients. Their "slow" nutrient release status occurs precisely because they contain organic matter. This is not a detriment, since it is organic matter that accomplishes what chemical fertilizers cannot: the improvement of soil physical structure, the enhancement of biological activity and the improvement of certain soil chemical properties. Organic fertilizers release their nutrients throughout the growing season and therefore, may match the needs of crop plant more exactly than chemical fertilizers.

Negative impact on production (na).

Other conflicts (na).

Recommendations before Implementing the Practice

This huge loss of nutrients associated with burning of topsoil has not only deteriorated soil fertility but also reduced the crop production and led to pollution of the environment and atmosphere. Therefore, the losses of the topsoil by stubble burning have serious disturbance to the society and habitat and would be detrimental to the functioning of relevant ecosystem, environment and atmosphere. The present investigation insight an increasing awareness about the status of soil degradation and environmental pollution induced by the burning of topsoil through this method of land preparation.

Conclusion

Therefore, amendment of animal manure after slash and burn system of land clearing in tilled plots is a development practice that promotes soil management that are maximizing CO_2 sinks while minimizing NO_2 and CO emissions and maintaining crop yields which is required to reduce agriculture's contribution to climate change.

Potential barriers for production

Barrier	YES/NO	Explanation (short, referenced)
Biophysical	Yes	Burning vegetation residues after slashing exposes the soil surface to direct contact with rain. Exposed soil surface erode easily with rainfall impact leaving rills on the field. Erosion takes away the fertile topsoil of the field. More so, the exposed soils can be easily erode wind
Cultural	Yes	Previously, when "slash and burn" was encouraged by farmers, they practiced land rotation where after some time when the soil has lost its fertility. They leave the land and move to a fertile one while the previous regain its fertility. After burning the land severally, it takes between 7 to 15 years to regain its fertility. The practice of leaving the land fallow for that long is more difficult now with the growing population and increasing demand for food.
Social	Yes	Slash and burn causes air pollution. Destroys; insects and animals habitats. Destroys pastures and water shed points. Contributes to global warming.
Economic		
Institutional		
Legal (Right to soil)	Yes	As a way of community intervention, Community by-laws on bush burning are enacted.
Knowledge	No	Majority of the farmers lacks knowledge of providing appropriate fire proof tracks and the right time of set the fire. Thus, avoiding burning of residual vegetation after slashing can save one from environmental troubles, while we protect our forest cover. It goes a long way to improving climatic conditions.
Natural resource		Uncontrolled burning on farms has been a major cause of bushfires spreading to destroy vast areas of forests, plantations and other properties. Farmers annually are troubled with litigation concerning fires that burnt their farms or another's farm. Slash and burn has been a major cause of deforestation worldwide.
Other		Lack of community sensitization on dangers of bush burning during the farming season is one of the potential barriers for production.

Plate 1: Experimental fire and layout of plots during slash and burn method of land preparation.

Plate 2: Growth performance of sweet potato (*Ipomea batata*) receiving different treatments under slashes and burn method of agriculture at ten weeks after planting.

Plate 3: Cured cattle-cud digester (animal manure) ready for application on slash and burn plots as a soil amendment for potato cultivation.

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