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Research article

Critical Issues of Agricultural Burning on Soil Health and Atmospheric Greenhouse Gases (GHGs) Concentration

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Abstract

Biomass burning is responsible for about a quarter of global carbon monoxide emissions, just under half of particulate aerosol emissions, and a large but poorly quantified fraction of tropospheric ozone precursor emissions. Research has shown that occasional burning of straw, stubble, and grass may provide the producer with an economical and effective management tool and in some cases increase small grain and grass production in the short-term. However, the same research has shown that repeated, long-term burning of straw or grass (pastures) can have a more permanent negative effect on soil quality and overall soil health. Repeated burning can cause long term reduction in yields. These long-term losses in yield cannot be offset by the addition of fertilizer. Additionally, soils that are high in fertility may take several years to show the detrimental effects of burning. However, research has furnished concrete evidence of the slow but sure consequences of repeated burning of grass or stubble to soil health. Furthermore, what may look like a savings in fertilizer, pesticides for weed control, or insecticides for insect control, will eventually turn into increased long-term costs to maintain productivity due to continual loss of organic matter, organic nitrogen, organic carbon, and the size and quantity of microbial pools.

Key words: Climate change, biomass, burning, GHGs, ozone, soil productivity

Introduction

Slash-and-burn method of land clearing, according Edem [1] is the traditional method of agriculture and has been an integral part of shifting cultivation widely practiced by over 90% of farmers in South Eastern Nigeria. As the traditional shifting cultivation paved way to continuous cultivation, necessitated by demographic pressure, coupled with burning, the detrimental effect of soil degradation became prominent. Higher surface temperatures often enhance seed germination and plant growth as well as cause deeper annual soil thawing. This effect is significant, as it can increase both the depth and the temperature of the rooting zone. All of these effects, combined with increased nutrient availability, are hypothesized as being the reason why plant growth is often stimulated following a fire [2]. Fires can either reduce or increase soil moisture. Reduction in soil moisture occur when increased soil temperature decrease water viscosity, thus allowing more water to percolate through the soil profile. In addition, reduced shade, combined with increase soil temperatures also result in higher evaporation rates, which in turn, restricts the movement of water into the soil profile [2]

Fire is a powerful and rapidly acting modifier of the soil environments. Although soil properties are a dominant factor in determining distribution and productivity of plant communities, and despite studies of many aspects of vegetation burning, data available quantifying the sudden modifications induced by passage of fire on soil are limited. This significant gap in knowledge contributes to the poor understanding of mode of action of fire on soil ecosystem. Characteristics of ecosystems are altered both as sudden passage of fire and also as delayed changes derived from simultaneous modifications of the physical and chemical compositions, the plant covering capacity and biological spectra. Sudden modifications are very striking and immediately perceptible, but the delayed change leaves their mark on the soil and determine it future evolution [3]. Vegetation burning, both natural and human-induced, is a major cause of air pollution. Particulates, tropospheric ozone, and carbon monoxide are toxic to humans as a result of biomass burning [4].

Also, the soil environment, during and immediately after passage of fire, is affected directly by input of heat and ash. In the field, the effects of these two factors are concomitant, thus making identification of individual causes of changes in the soil difficult. This suggest that one of the ways to study the sudden modification induce by fire on ecosystem carefully is through measuring the various soil parameters and GHGs [5] before and during/immediately after performance of experimental fire on vegetation. This will help to ascertain the sudden modifications of soil physical and chemical properties, and air quality induced by fire and its implication on soil productivity

Discussion

Agricultural Burning as a Land Management Tool:

The invention of deliberate fire ignition and its control by man started the anthropogenic modification of biosphere [6]. Fire has long been recognized as a disturbance that maintains grasslands and savannas and prevents invasion of woody species (Plate 1) [7,8,9] Therefore, prescribed fire is often employed as a land management tool to suppress the encroachment of woody plants into grass-dominated ecosystems.

In savannah ecosystems, the balance between trees and grasses, stand structure and dynamics, and shrub cover and abundance is determined to a large extent by fire frequencies and interactions between fire and other disturbance factor [10, 11, 12, 13]. Above and below ground productivity often increase following fire as a result of microclimatic modification due to removal of litter and standing crop, and changes in nutrient availability and distributions [14,15,16,17,18,19,20]. Most land that is left unused in a cropping year is being set on fire by farmers. This is common with the livestock farmers, for the animals to browse on young plants that grow after burning. Before the plants come up to cover the ground surface, the soil is exposed to climatic element of rainfall. Subsequently, soil aggregates are dispersed; pores are clogged with particles and further result in much higher rates of surface run off [12] The level of alteration may even be enormous if quantity of trash is large and the residence time of burning is long, or a thin, dry litter is completely incinerated [22]. More severe burns may alter such fundamental characteristics as texture, mineralogy and cation-exchange capacity [23]

Effect of Biomass Burning on Soil Physical Properties

Aggregate stability: Burning has been identified as one of the soil degrading practices that result in structural degradation [24,25,26]. Even then, it was reported by Obale-Ebanga *et al.,* [27] that burning increases the percentage macro-aggregate stability of surface soil vertisol. Kavdir *et al.,* [28] also reported that fire influence soil aggregate stability due to consumption of soil organic carbon and changes soil organic matter constituents.

Porosity and bulk density: Reduction in larger pores and total porosity following burning has been reported [29,30,31]. It therefore appears that the reduction in macro pores and total pore volumes was perhaps due to ash deposits in larger pore. The ash deposited might have probably reduced the large pore density and concomitantly increased the soil density [29,30]

Particle size distribution: Burning has also been shown to affect soil particle size distribution [21,23,26]. reported increased in silt fraction after burning. This was attributed to aggregation of finer particles (clay) into larger particle silt-size particles.

Moisture retention: Hubbert *et al*., [26] reported reduction in moisture content from 0.13 to 0.03 m^3m^{-3} at a depth of 0-0.5m in a steep chaparral watershed, southern California, following burning. The results however contradict with those of Mallik *et al*., [29] who reported an increase in water retained after burning. The reduction in soil moisture apart from decrease in clay fractions or loss in soil organic matter [32].

Saturated hydraulic conductivity (K_{sat}): The major determining factor of K_{sat} is the amount of disturbance to the surface of the material by fire, which is usually organic debris that protects the underlining mineral soil. [25] found that K_{sat} of soils decreased approximately 50% in the burnt plots relative to adjacent unburned plots.

Effect of Fire on Soil Chemical Properties

Soil pH and electrical conductivity (EC): Hermandez *et al*., [33] reported that EC values of burnt plots were greater than that of unburned plots. Burning of organic matter releases ash and charcoal to the soil. Ash contains the inorganic element such as basic cations- Ca^{2+}, Mg^{2+} and K^+ in the ash which lead to increase pH and EC. A study conducted in Chile showed that fire increased soil pH [34]. An increase in pH from 4.5 to 7.6 was observed in the surface 1.25 cm in soils after fire in Western Oregon and Washington [35]. This increase of pH persisted after 2 years though it had dropped to 5.7 compared to 4.7 for the unburned areas. Increases in pH following fire were also reported by [36].

Organic carbon/organic matter: Loss of organic carbon was observed by [37] According to these researchers, the reason for carbon loss from the burnt soil was volatilization of organic carbon and conversion of organic matter to ash. [38] also reported that organic carbon losses were higher than 50% in the upper 10 cm of humid under pine forest was observed after wild fire. It has been reported that loss of carbon in soil occurs as a result of fire depleting the litter on the soil surface [39].

Total nitrogen: Burning has been reported to increase the availability of soil nitrogen [40, 41, 42, 43, and 44]. However, total nitrogen content in the surface and O-horizons has been reported to decrease following fire [35, 45]. Nitrogen losses can occur during fire period *via* volatilization and after fire there could be an increase in biological nitrogen (N_2) fixation as a result of increasing mineralization rate in the soil [46,47].

Carbon to nitrogen ratio: In many ecosystem, microbial C and N increases after the first year of burning and decrease after prolonged annual burning compared to unburned soils[48,49,50,51]. Vegetation fire has also been observed to alter plant tissue chemistry by increasing C to N ratio of shoots and root [15,19, 4] reported that C and N mineralization decreases after fire and did not recover after 9 months of study period.

Basic cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) and available P: The ash deposits after burning, helps to fertilize the soil. This is done by immediate release of the occluded mineral nutrients (Mg, Ca, available P), for crop use [52,48,53] also submitted that increased soil temperature after burning, stimulate biological activity, increases organic matter mineralization to enhance nutrient availability. [3] reported that K^+ content was significantly higher in burned forest 21 months after fire. Soil Ca^{2+}, Mg^{2+}, Na^+ and K^+ have also been found to increase following burning [35,42,44] .The change of soil available P content generally depends on soil temperature during the fire and tends to increase in burned soils [53,47,54] reported that plant and plant residues turn back to the soil as ash following fire, if it is not carried out by wind or run off. [39] reported that burned surface soils tended to have higher concentrations of non-combustible elements such as Ca^{2+}, K^+, Mg^{2+} and P compared with unburned soils.

Soil organic carbon and nitrogen stocks: Fire has the potential to influence ecosystem carbon storage and dynamics by changing plant species diversity and dominance, plant tissues chemistry, primary productivity, decomposition of soil organic matter and characteristics of the physical environment [10,11,12,13]. Fire may maintain soil carbon stocks than long unburned soils but depends on frequency and intensity [5,39] reported loss of carbon in soil as a result of fire depleting the litter on the soil surface. Soil organic carbon and total Nitrogen storage have remained unchanged after 15 years of annual fire in the North American tall grass Prairie [19]. It has also been reported by Roscoe *et al*., [55] that biannual fires for 21 years has no effect on soil organic carbon storage in the upper 1m of the profile in Brazilian cerrado. In contrast, 30 to 50 years of annual or biannual fire in grass lands and savannas in Zimbabwe [56] and South Africa [57, 58,59] reduced soil organic carbon by 10 to 30%, where as soil total nitrogen storage remained constant or decreased by up to 20% in the upper 30 cm of the profile relative to unburned plots. Wan *et al*., [20] reported that fire generally results in no net change in soil total nitrogen. However, it was reported that annual burning caused a 25% increase in root growth compared to unburned controls and hypothesized that plants increased allocation to roots to compensate for N limitation in burned areas [19].

Role of Biomass and Fossil Fuel Combustions on Climate Change:

Increase in atmospheric greenhouse gas (GHG) concentrations is currently a concern because of their role in climate change. Concentration of these gases in the atmosphere has increased since the beginning of large-scale industrialization in the late 90s [60]. Agriculture alone contributes about 20% of the annual increase in radiative forcing (ability of 1 metric ton of a GHG to trap heat relative to a ton of carbondioxide (CO_2) through emission of methane (CH_4), nitrous oxide (N_2O), and CO_2 (**Plate 2**) [38] An additional 13% annual increase from land clearing via burning raises this contribution to about 33% to a large extent, emission of these gases depends on agro ecosystem management and soil properties. Soil properties are a product of soil-forming factors including landscape variability, agro-ecosystem management, and climatic factors. Development and promotion of soil management practices that are maximizing CH_4 and CO_2 sinks while minimizing N_20 and CO_2 emissions and maintaining crop yields are required to reduce agriculture's contribution to climate change [61].

Atmospheric concentration of several green house gases (GHG) has changed drastically since the industrial revolution because of biomass burning and other factors like fossil fuel combustion etc. the concentration of CO_2 responsible for 62% of the total radiative forcing by earth, has increased by 35% from 280% in 1980 to 377% in 2004. The concentration of methane (CH_4), responsible for 20% of the radiative forcing of the earth, has also increased by 155% from about 700 ppb around 1750 to 1785 ppb in 2004. the atmospheric concentration of nitrous oxide (N_2O), responsible for about 6% of the radiative forcing of the earth has increased by 18% from about 270 ppb around 1750 to 318.6 ppb in 2004 [62]. According to [60, 61] soil cultivation is not as obvious a source of atmospheric CO_2 as are fossil fuel combustion, deforestation, and biomass burning. Yet world soils have been a dominant source of CO_2 ever since the dawn of settled agriculture.

Conclusion

Traditional slash and burn method of land clearing is considered to be one of the most aggressive system of land clearing, leading to a reduction in available phosphorus, C:N ratio, clay, total porosity and 1mm, 0.5 mm and 0.25 mm aggregate size. The sudden increase in Ca, Mg, Total nitrogen, soil carbon stock is short live, because greater portion of these ions will be lost through erosion. These significant changes in soil properties in the upper 15 cm layer in the burnt plot compared with the sub-soil of the burnt plots and both layers of pre-burnt soil could be attributed to heating temperature and soil disturbances. In the same way, contribution of biomass burning to emission of green house gases in the burnt plots evident the contribution of slash-and-burn method of land clearing to the depletion of ozone layer. The result of this review indicates the need for a review of the method of land clearing for sustainable agricultural production. Therefore, sequential soil samplings should be carried out after slash-and-burn land clearing say, forth-nightly and monthly to assess further changes in the soil. Finally, slash-and-burn method of land clearing should be discouraged on arable farmland since the immediate mineralized nutrients are short-live; rather slash-and-mulch agriculture is suggested for the conservation of our soils.

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Plate 1: Agricultural burning experiment at University of Uyo Teaching and Research Farm.

Source: Edem *et al*. (2013)

Plate 2: Global GHG emissions during experimental fire passage on arable land.
Source: Edem *et al.* (2013)