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Full Length Research

Biostimulatory and carbon sequestration potentials of neem seed-based fertilizer formulation in nicosulfuron contaminated soil

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ABSTRACT: Neem seed cake has been reported to make nutrients available to support good growth of crops and increase yield. This ease of nutrient release is also required in a potential bio-stimulant. This study assessed the potentials of a neem seed-based fertilizer formulation as a bio-stimulant to aid continued nutrient mineralization from an organic source in contaminated soil samples. Neem seed-based organomineral formulation was added to soil samples contaminated with two field rates (40 and 60 mg.a. i ha^{-1}) of nicosulfuron herbicide to assess their separate and interaction effects on soil microbial activity in the laboratory. The treated samples were incubated for 8 weeks, and soil microbial activity was monitored in dynamics for the period of incubation. Data on soil basal respiration, soil organic carbon, and soil carbon mineralization quotient (qM) were collected on weekly basis for the 8 weeks. Application of nicosulfuron alone regardless of rate repressed soil basal respiration; hence carbon mineralization in the early weeks of the incubation period, but these parameters were stimulated after the 5th week of incubation. Addition of the neem formulation on the other hand caused consistent significant stimulation from the beginning to the end of incubation. Results further showed that combining nicosulfuron and the neem formulation raised soil basal respiration significantly above what individual factor contributed. It was therefore concluded that although the individual factor was found to increase CO_2-C compared to the control at the end of incubation, the interaction of the two inputs raised CO_2-C even higher. This is an indication that the neem seed cake formulation has the potentials to cushion the adverse effects of nicosulfuron contamination on the soil microbial community.

Keywords: Biostimulation mineralization quotient, neem seed cake, nicosulfuron, soil respiration.

INTRODUCTION

The Neem seed cake (NSC) is a byproduct of oil extraction and *azadiractin* isolation process of neem seed kernels (Elnasikh et al., 2011). The neem seed cake had been found to possess high soil nutritional value; hence the ability to improve growth in crops (Ketkar and Ketkar, 1995; Agbenin et al., 1999). It contains more nitrogen (2 to 5%), phosphorus (0.5 to 1.0%), calcium (0.5 to 3%), magnesium (0.3 to 1 %) and potassium (1 to 2 %) than farm yard manure or sewage sludge (Radwanski and Wickens, 1981). Soon and Bottrel (1994) described the neem seed cake as a natural fertilizer and as such a favoured input in agricultural production. The high soil nurishing potentials of the neem seed cake have been attributed to its ability to enhance soil biological, physical and chemical properties (Parmar, 1986), and therefore able to activate the microbial biomass, improves soil structure, increase water holding capacity and aggregate stability (Ketkar and Ketkar, 1995; Renuka and Sanka, 2001). NSC also acts as nitrification inhibitor to improve nitrogen use efficiency of mineral fertilizers (Agbenin et al., 2008).

Nicosulfuron is a prominent member of sulfonylurea derivatives commonly referred to as “third generation” herbicides. This group of herbicides have broad spectrum of action and a biological activity much higher per unit of active ingredient than most products on the market (Sofo et al., 2012). Third generation herbicides exhibit good selectivity in cereals and are highly active in the soil against a wide range of broadleaved weeds (Šantrić et al., 2014). The persistence of these herbicides in the soil is however of great significance because of their high soil activity. This could have implications for the safety of sensitive rotational crops and the status of soil microbial indices. Research has shown that using herbicides for weed control may adversely affect the soil microbial status (Adejoro et al., 2018). Studies have also revealed that the sulfonylurea herbicides influence soil microbial activity and biomass in a variety of ways (Saeki and Toyota, 2004; Djuric and Jarak, 2006; Vischetti et al., 2000; Zabaloy et al., 2008). Nicosulfuron is gradually gaining prominence in West Africa where it is rapidly replacing atrazine because of the failure of the later to provide season-long weed control in maize fields in recent times (Aladesanwa and Adejoro, 2009). Microbial degradation is the major pathway for sulfonylurea dissipation, hence farm inputs capable of enhancing microbial activities such as the neem seed cake is therefore expected to be complementary to this group of herbicides with respect to conferring enhanced degradation on them through the process of bio-stimulation. Farm inputs interact with one another to affect the quality of the soil and environment. The interaction may however favor or be detrimental to environmental quality. Carbon sequestration and mineralization are two environmental processes that have gained prominence in recent times because they are strongly connected to environmental quality in the global scale. These processes are however influenced by farm management practices that are capable of stimulating soil microbial activity. Practices that encourage soil microbial activity accelerate the process of carbon mineralization, hence depleting the soil carbon stock by increasing CO_2 release into the atmosphere from the atmosphere.

Neem seed-based fertilizer (Royal Fertilizer Plus ®) is a commercial organomineral formulation, which is a blend of neem seed cake with suboptimal rates of nitrogen, phosphorus and potassium (NPK). Neem seed-based formulation has been found to combine dual attributes of quick and sustained nutrient release to support optimum growth and yield in arable crops (Ketkar and Ketkar, 1995; Renuka and Sanka, 2001). However, its effects on soil microbiological parameters have scarcely been researched. This study was motivated by the idea that the information obtained might prove beneficial in evaluating both the magnitude and direction of the impacts of these farm inputs on the agro-ecosystems, particularly as relates to the evolution of CO_2 (a major greenhouse gas) from the soil. The outcome will be useful to farmers, environmentalists and all stakeholders to locate their interests in application of farm inputs. Thus, the main objective of this study was to determine the combined effects of nicosulfuron herbicide and neem seed-based fertilizer on soil carbon mineralization and mineralization quotient as a measure of ability of their interaction to perturb the carbon cycle.

MATERIALS AND METHODS

Study area

Top soil was sampled once (0 to 15 cm depth) from the experiment station of the Department of Crop, Soil and Pest management, Federal University of Technology, Akure, Nigeria ($7^0$16´N and $5^0$12´E). Sampling was done in an area in the field having no pesticide treatment history during the last four years. This was to preclude native soil pesticide residues that might interfere with the result. The samples were transported to the laboratory in sealed polyethylene bags to be further processed. Pre-treatment soil physico-chemical analysis of the soil indicates 31.2% clay, 52.8% silt, 16% sand with 1.82% organic carbon, 1.5g kg^{-1} of soil total nitrogen, 10.8 mg kg^{-1} available phosphorus and 0.42 Cmol kg^{-1} available potassium. The pH of the soil was found to be 5.5 (1: 2 H_2O).

Soil sample preparation

In the laboratory, soil sample were sieved (<2 mm) to remove plant materials, soil macro fauna and stones because activities may interfere with the results of soil respiration. After sieving, the soil samples were homogenized and water holding capacity (WHC) was adjusted to 60%. This was achieved by first bringing the soil to field capacity; thereafter the WHC was brought down to 60% by oven-drying. The samples were finally kept in a plastic box, and stabilized at 30°C in the dark for one week. A portion of the stabilized soil samples (500 g) was transferred into glass jars to be simultaneously treated with nicosulfuron (Accent 75 WG, DuPont Poland) and the Neem seed-based fertilizer. The control and treated soils were incubated in moist condition at room temperature (28^0C) throughout the incubation period. This condition was adopted following reports that maximum growth and activity of microorganisms occur under such conditions (Alexander, 1977).

Preparation of fertilizer and herbicide treatments and experimental design

The Neem seed-based fertilizer (NSBF) was obtained directly from the manufacturer (Royal Fertilizer Plus ®)

while the nicosulfuron herbicide was obtained from local agro dealers in Akure, Nigeria. NSBF was applied at the manufacturer's recommended rate of 300 kg ha^{-1} in factorial combination with two field rates (40 and 60 mg. a. i ha^{-1}) of nicosulfuron herbicide. Each factor included a control jar with equal amount of soil that that received no amendment. This makes the design a 2 by 3 factorial experiment in completely randomized design (CRD), and individual treatment combination was replicated three times. The conversion of the field application rates of NSBF and nicosulfuron into mg/kg of soil was done assuming even distribution in 0 to 15 cm depth of soil with a soil bulk density of 1.5 g cm^{-3}. The NSBF was thoroughly mixed with soil samples before transferring soil into the jars while calculated amounts of nicosulfuron doses were dissolved in water and added to the soil inside the jars. The control soil samples received equal volumes of sterile distill water. The glass jars were then made airtight and incubated at room temperature for a period of 12 weeks. The moisture condition of the soils was maintained at 60% maximum water holding capacity by the addition of sterile distill water once every 2 weeks throughout the incubation period. To achieve this, the initial weight of the jars were determined and recorded at the beginning of incubation. These weights were confirmed every two weeks, and any deviation, which indicated moisture loss, was corrected by adding water to arrive at the original weight.

Determination of physico-chemical properties of soil

Soil texture, pH, Organic matter and nutrient status of the air-dried soil sample were determined following standard methods (AOAC, 1990). Soil samples were analyzed for total N using Kjeldahl (1883) digestion and distillation method. Available phosphorus was by the Bray 1 method, exchangeable K, Ca and Mg were determined by extraction with 1M ammonium acetate at pH 7.0. K, Ca and Mg contents were determined with flame photometer. Soil pH (1:2 soil-water) was determined using a pH meter, while organic matter (OM) was determined by dichromate oxidation method (AOAC, 1990).

Measurement of basal respiration (SBR) and carbon mineralization quotient (qM) of soil

Basal respiration (µg CO_2-C g^{-1} soil) was determined by the alkali sorption-titration method described by Anderson and Domsch (1990). A 10 mL solution of 0.5 M NaOH was dispensed into a 50 mL beaker and placed inside the plastic jars containing the treated soil to trap CO_2 evolved from the soil. The trapping solutions were replaced after titration on weekly basis and covered back with lids (air tight seal). At the end of each week of incubation, 5 mL of 1.0M $BaCl_2$ was added to the solutions from the jars to precipitate carbonate (as $BaCO_3$), thus facilitating the determination of CO_2 evolution (in µg CO_2-C g^{-1} soil) from the treated soil. The evolved CO_2-C was then determined by titration. Sodium hydroxide (NaOH) in solution was titrated against 0.5 M HCl using phenolphthalein indicator. Two blanks without soil were prepared to assess the amount of CO_2 trapped without respiratory activity. Carbon mineralization quotient (qM) was measured at the end of incubation. This was taken as the ratio of CO_2-C (µg CO_2-C g^{-1} soil) to organic carbon (mg g^{-1} soil).

Data analysis

Data collected from the experiment were subjected to a two-way analysis of variance (ANOVA) while treatment means, which include both the main and interaction effects of the different factors were compared using the Tukey test ($p<0.05$). Graphs and bar chats were prepared using Microsoft Excel® (2016 version). Error bars were determined using standard error.

RESULTS

Results of the main effects of nicosulfuron and NSBF treatments on soil basal respiration indicated a consistent stimulation of CO_2-C production by the organomineral formulation for the entire span of the experiment (Figure 1a). Both rates of nicosulfuron however repressed carbon mineralization in the first 5 weeks in a manner that is negatively related to rate of herbicide application (Figure 1b). The reduction in CO_2-C emission was significant ($p<0.05$) only in the 4th and 5th weeks of incubation, and this was followed by a stimulation of this parameter by the nicosulfuron herbicide starting from week 6 up to the termination of the experiment (Figure 1b). Within the first 5 weeks after incubation, carbon mineralization as influenced by the herbicide appeared to be rate dependent, and this effect faded to no significance ($p<0.05$) in the last 3 weeks of incubation (Figure 1b).

The presence of neem fertilizer generally raised carbon mineralization in the herbicide treated samples regardless of rate of application (Table 1). Application of neem fertilizer alone produced less volume of CO_2 compared to when the herbicide was present. Carbon mineralization was noticed to be relatively high between 4 and 8 weeks after incubation (Table 1). CO_2 production was found to be 200% higher at the termination of the experiment compared to the production at the beginning of incubation (Table 1).

The main effects of fertilizer (Figure 2a), and herbicide (Figure 2b), reveal that application of the NSBF did not significantly ($p<0.05$) increase organic carbon (OC) in most part of the incubation period, although the value of this parameter was slightly increased starting from the 4th

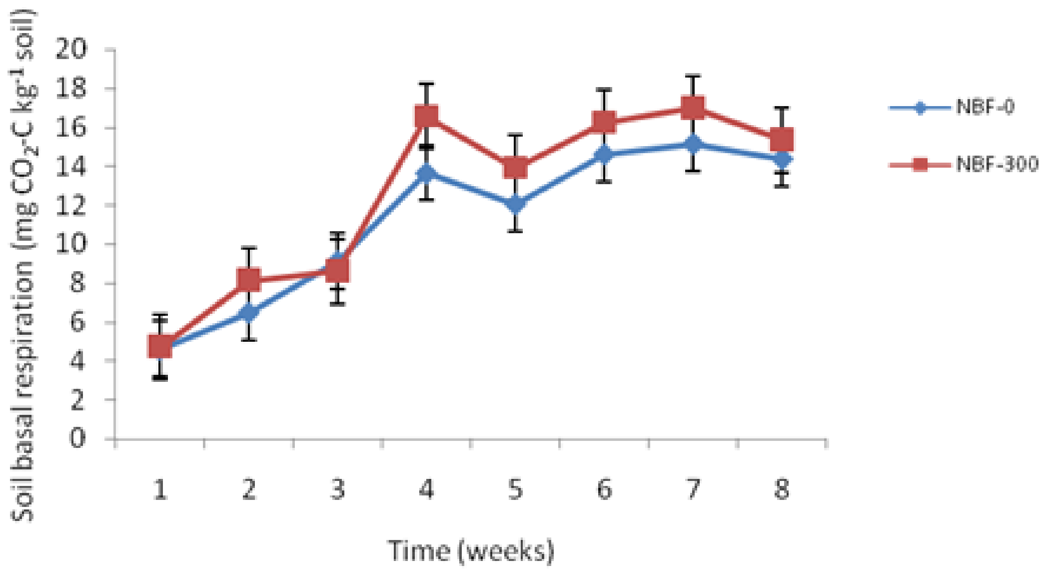

Figure 1a. Main effects of Neem seed cake on soil basal respiration.

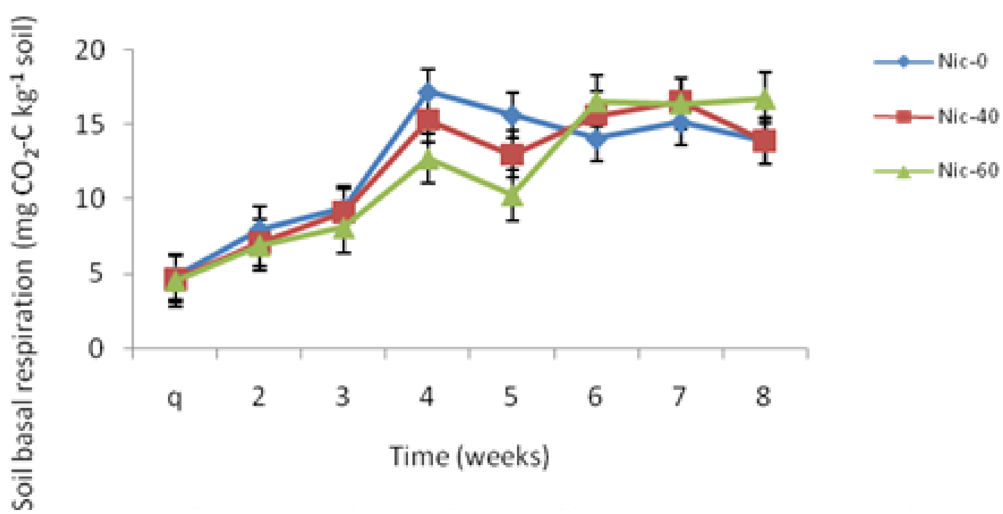

Figure 1b. Main effects of nicosulfuron treatment on soil basal respiration.

Table 1. Effects of fertilizer- herbicide interactions on soil basal respiration (mg CO_2-C g^{-1} soil).

Fertilizer	Herbicide	Weeks after treatment application							
		1	2	3	4	5	6	7	8
	Nic-0	4.2^a	6.8^a	9.0^a	15.0^b	13.5^b	13.0^d	13.9^d	13.4^b
NBF-0	Nic-40	4.8^a	6.7^a	8.8^a	14.4^{bc}	12.8^b	15.0^c	15.0^{cd}	13.5^b
	Nic-60	4.8^a	6.0^a	8.0^a	11.6^c	9.9^b	15.1^c	16.4^{bc}	14.6^a
	Nic-0	4.2^a	7.5^a	8.2^a	13.9^{bc}	10.7^b	15.9^{bc}	16.6^{ab}	16.6^a
NBF-300	Nic-40	4.5^a	7.8^a	9.9^a	16.3^b	13.2^b	16.3^b	16.6^{ab}	14.4^b
	Nic-60	5.4^a	9.1^a	9.3^a	19.4^a	17.8^a	17.3^a	17.9^a	17.0^a

Means in a column followed by the same letter(s) are not significantly ($p<0.05$).

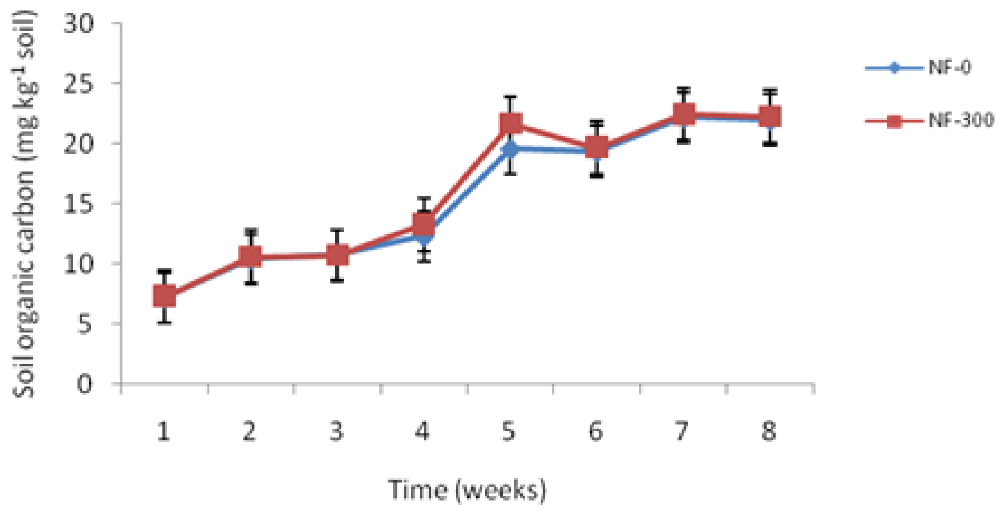

Figure 2a. Main effects of Neem seed cake on soil organic carbon concentration.

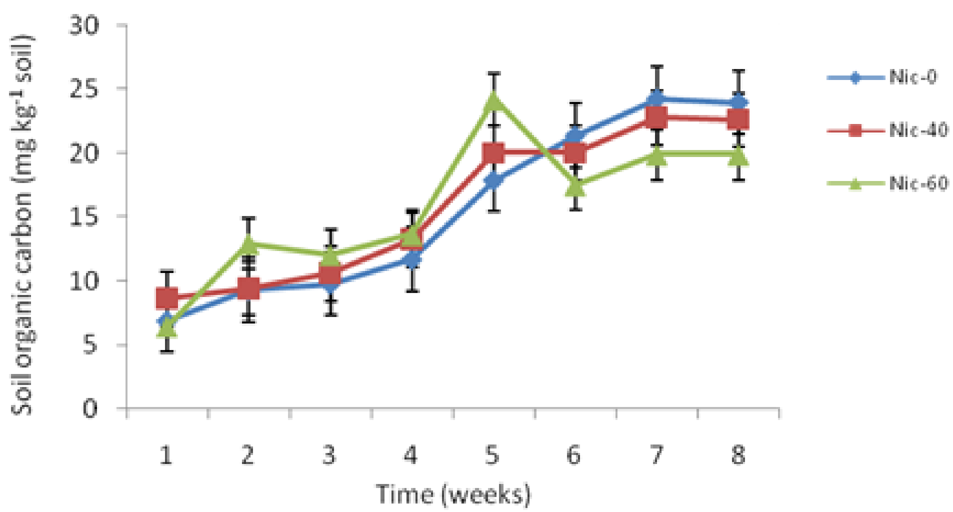

Figure 2b. Main effects of nicosulfuron on soil organic carbon concentration.

week up to the termination of the experiment (Figure 2a). Organic carbon was found to be higher in the jars treated with nicosulfuron from the beginning of incubation to the 5th week after treatment application than in the untreated control, and this was followed by a significant reduction in soil OC up to the end of incubation. In most parts, the higher dose of the herbicide caused significant reduction in soil OC (Figure 2b).

The response of soil OC to the interaction between nicosulfuron and the NSBF are presented in Table 2. Organic carbon measured in dynamics as influenced by fertilizer – herbicide interaction did not follow any consistent trend. Higher levels of OC were however recorded in jars in which the NSBF was applied without the herbicide. Application of the lower rate of nicosulfuron alone did not significantly ($p<0.05$) influence OC in most parts of the incubation period (Table 2). Organic carbon concentration was also found to be raised by the addition of the fertilizer to the herbicide contaminated jars.

Figures 3(a) and 3(b) summarize the effects of the herbicide and fertilizer on carbon mineralization quotient (qM). NSBF application when considered regardless of the herbicide increased qM from the start to the end of incubation. Nicosulfuron on the other hand reduced this parameter from the start to the 4th weeks but later stimulated qM towards the end of incubation. These alterations were noticed to be inversely related to the application rate of the herbicide.

Table 2. Effects of fertilizer – herbicide interactions on soil organic carbon (mg g^{-1} Soil).

Treatment combinations		Weeks after treatment							
		1	2	3	4	5	6	7	8
	Nic-0	6.6^{c}	8.7^{b}	9.4^{d}	11.7^{b}	13.6^{d}	18.5^{b}	21.0^{b}	20.9^{b}
NF-0	Nic-40	7.1^{bc}	9.9^{b}	10.2^{bcd}	11.^{b}	22.1^{abc}	16.3^{b}	18.6^{b}	18.6^{b}
	Nic-60	6.1^{c}	9.6^{a}	11.4^{abc}	14.0^{a}	20.3^{bc}	17.8^{b}	19.5^{b}	19.5^{b}
	Nic-0	9.0^{a}	13.0^{a}	12.3^{a}	14.2^{a}	24.9^{a}	24.2^{a}	27.6^{a}	27.1^{a}
NF-300	Nic-40	8.1^{ab}	12.7^{a}	11.7^{ab}	13.0^{ab}	23.4^{ab}	23.6^{a}	27.0^{a}	26.6^{a}
	Nic-60	6.7^{c}	9.2^{b}	9.7^{cd}	12.3^{ab}	19.6^{c}	17.1^{b}	20.3^{b}	20.3^{b}

Means in a column followed by the same letter(s) are not significantly ($p<0.05$).

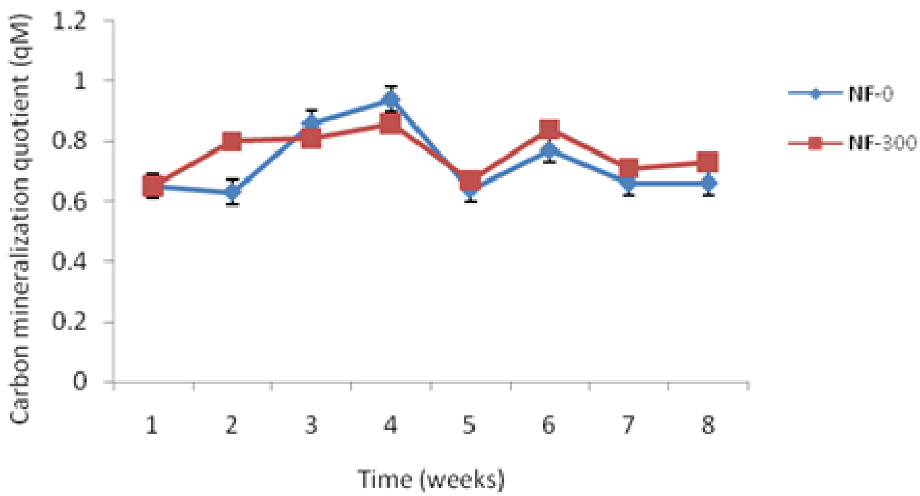

Figure 3a. Main effects of neem seed cake on soil qM.

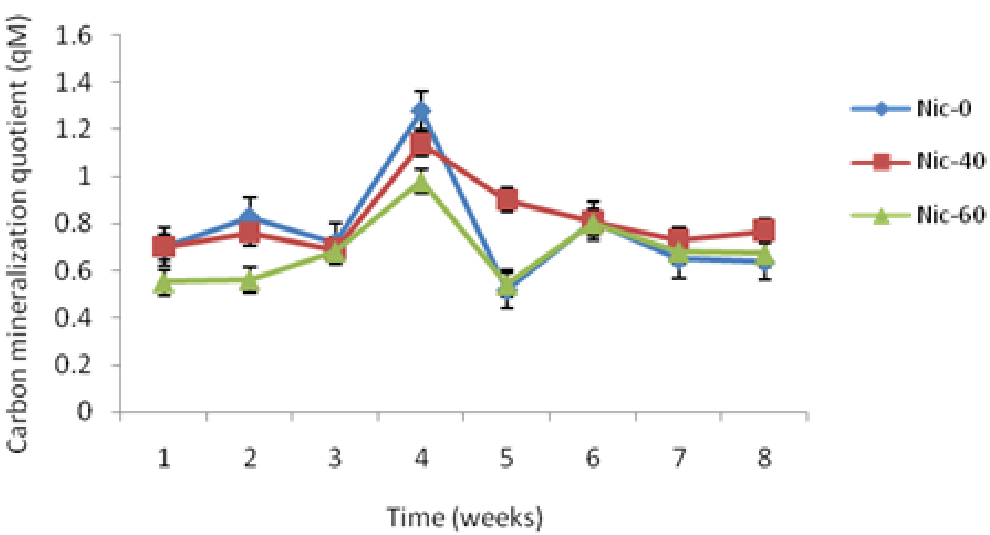

Figure 3b. Main effects of nicosulfuron on the soil qM.

Table 3. Effects of fertilizer – herbicide interactions on soil carbon mineralization quotient (qM).

Treatment combinations		Weeks after treatment							
		1	2	3	4	5	6	7	8
	Nic-0	0.79a	0.92a	0.85ab	1.28b	1.00a	0.92a	0.77a	0.85a
NF-0	Nic-40	0.54a	0.58b	0.75b	1.02cd	0.51c	0.66c	0.54b	0.57bc
	Nic-60	0.64a	0.61b	0.79ab	0.83d	0.49c	0.73bc	0.67ab	0.77ab
	Nic-0	0.56a	0.74ab	0.81ab	1.68a	0.55c	0.69c	0.58b	0.52c
NF-300	Nic-40	0.76a	0.53b	0.81ab	1.26bc	0.56c	0.88ab	0.76a	0.71abc
	Nic-60	0.63a	0.90a	0.96a	1.13bc	0.81b	0.94a	0.80a	0.77ab

Means in a column followed by the same letter(s) are not significantly ($p<0.05$).

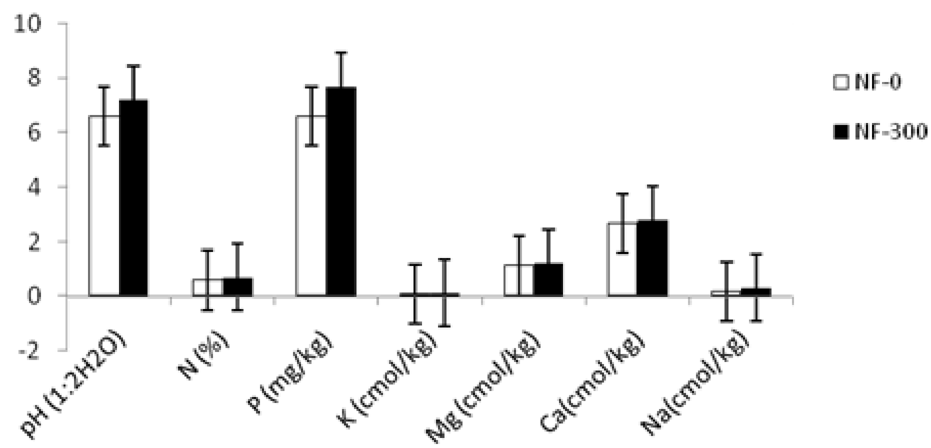

Figure 4a. Main effects of neem seed cake on soil nutrient composition.

Results in Table 3 indicate a reduction in soil carbon mineralization quotient (qM) with the addition of nicosulfuron irrespective of rate of application, and this reduction was sustained to the end of the experiment. The presence of the NSBF however changed the trend as this parameter was noticed to increase in all the jars to which the fertilizer was added. This increase was significant for both rates of the herbicide at the 5th and 6th week of incubation.

Addition of the NSBF significantly raised soil pH, but the macro nutrients were not significantly influenced except K and Na, whose concentrations increased significantly in the fertilizer treated jars. The other macronutrients only showed slight increase in response to NSNF addition (Figure 4a). Only K and Na were found to responded significantly ($p<0.05$) to nicosulfuron contamination of soil samples (Figure 4b). The response of the nutrient elements to the herbicide was also not consistent with the rate of nicosulfuron application. Addition of NSBF to the soil contaminated with nicosulfuron was found to increase the pH appreciably (Table 4), and although not significantly, addition of the fertilizer slightly increased soil residual N and P. the exchangeable cations (K, Mg, Ca and Na) were not affected by the presence of the fertilizer in any consistent manner, but their levels were also increased by the fertilizer in most parts.

DISCUSIONS

The sustained increase in soil respiration after application of neem seed based organomineral formulation was presumably caused by the ability of microoganisms in the soil to metabolize the neem seed-based fertilizer. Results obtained by Elnasikh et al. (2011) revealed that when soil samples are incubated for eight weeks in the presence of neem seed cake, the neem seed cake stimulates the growth of the users of organic nitrogen. The formulation used in this study contained suboptimal rates of mineral N, P and K with a huge organic base. This organic fraction of the fertilizer probably served as a suitable substrate for native soil organisms. The sustained production of CO_2-C

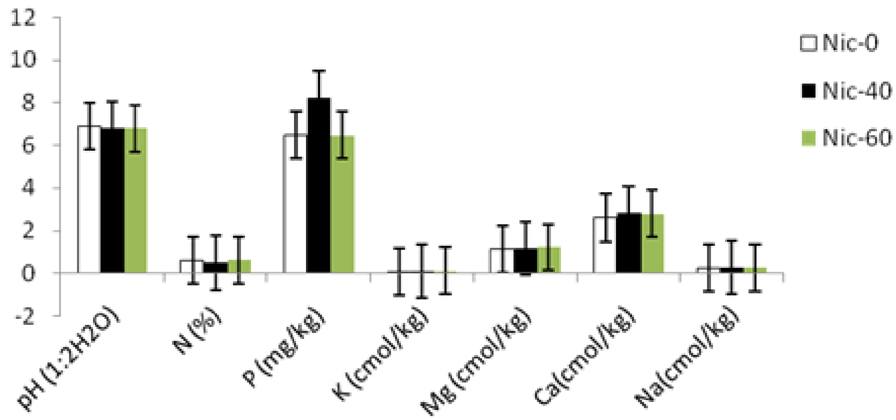

Figure 4b. Main effects of nicosulfuron on the soil nutrient composition.

Table 4. Effects of Nicosulfuron-Neem cake interactions on soil pH and nutrient composition.

Neem Fertilizer	Herbicide	pH (1:2H_2O)	N (%)	P (mg/kg)	K (cmol/kg)	Mg (cmol/kg)	Ca (cmol/kg)	Na (cmol/kg)
	Nic-0	6.65^{ab}	0.54^{a}	4.98^{a}	0.05^{d}	1.17^{a}	2.80^{a}	0.12^{d}
NF-0	Nic-40	6.43^{b}	0.53^{a}	8.30^{a}	0.11^{bc}	1.20^{a}	2.87^{a}	0.24^{b}
	Nic-60	6.65^{ab}	0.56^{a}	5.86^{a}	0.09^{c}	1.03^{a}	2.33^{a}	0.18^{c}
	Nic-0	7.22^{a}	0.56^{a}	7.98^{a}	0.14^{a}	1.13^{a}	2.40^{a}	0.34^{a}
NF-300	Nic-40	7.22^{a}	0.57^{a}	8.16^{a}	0.10^{c}	1.17^{a}	2.77^{a}	0.29^{ab}
	Nic-60	7.02^{ab}	0.63^{a}	7.08^{a}	0.13^{ab}	1.43^{a}	3.23^{a}	0.31^{a}

Means in a column followed by the same letter(s) are not significantly ($p<0.05$).

up to the end of incubation indicated that the soil contained a larger number of consumers of organic N and a smaller number of the chemo-autotrophs, whose population have been widely reported to be highly susceptible to neem products (Gopal et al., 2007; Kiran and Patra, 2003). The repressive action of the herbicide nicosulfuron on soil carbon mineralization in the first 5 weeks of incubation however confirmed the inhibitory potentials of sulfonylurea herbicides of soil microbial activities often reported in literatures (Saeki and Toyota, 2004; Djuric and Jarak, 2006; Ghinea et al., 1998; Radivojević et al., 2007). Pampulha and Oliveira (2006) observed an inhibition of cellulolytic bacteria (by 38 to 68%) after application of a combination of bromoxynil and prosulfuron herbicides. The inverse relation between CO_2-C production and nicosulfuron rate of application suggests that the toxicity is dose dependent as high dose may mean more concentration of active ingredient to suppress more microbial population. The stimulation in soil respiration noticed starting from the 6th week suggests that a fraction of the soil microbial community recovered from the stress to rapidly replace the sensitive species subsequently maintaining the metabolic integrity of the soil (Goswami et al., 2013). When pesticides are applied to the soil at sufficient and optimum concentrations, microbes are killed or reduced in number. However, the bacterial number increases quickly to reach a level far in excess of the untreated soil due to reduction in microbial competition (Adams, 2001) and use of cell debris of killed cells by the survivor population (Goswami et al., 2013; Adejoro, 2016). The effects of the herbicide on carbon mineralization appearing to be increasing towards the end of incubation was an indication that nicosulfuron dissipated with time after application and that its metabolites posed no detrimental effects on the soil microbial activity. Results from this experiment also agree with reports of Šantrić et al. (2014) that the effects of nicosulfuron on soil microbial activity depended on its application rate, and duration of activity, which can either be stimulating or inhibiting. The application of the NSBF to the herbicide contaminated soil raised CO_2-C production level by 55%. This may indicate that the organomineral formulation possesses bio-stimulatory potentials. de Lipthay et al. (2007) showed that the mineralization rate of a greater herbicide concentration is stimulated by the addition of nutrients. This is because nutrients like carbon, nitrogen, and phosphorus stimulate microbes to create the essential enzymes to break down the contaminants (Kanissery and Sims, 2011). Many bioremediation studies in agricultural fields and waste water have been conducted using nutrients from either organic manure or mineral fertilizer sources to stimulate native microbiota. Mwegoha et al., (2007) evaluated dissolved organic carbon (DOC) extracted from chicken manure for bio-stimulation and enhancement of perchlorate rhizo degradation and observed near 100% removal of perchlorate in 21 days and 11 days respectively for humic and sandy soils. The lack of nutrients in soil could suppress the mineralization of herbicide when they are used as carbon sources for microbial growth (Kanissery and Sims, 2011). The differences in the direction of response of soil respiration to the sole nicosulfuron application and its combination with the fertilizer in this study also suggests that the organisms capable of metabolizing the fertilizer are also able to cause a cometabolic decay of the herbicide (Adejoro, 2016).

Application of the NSBF only slightly increased organic carbon content of the soil but the increase was not significant ($p<0.05$). This could be attributed to the fact that the fertilizer is an organomineral formulation. An organomineral formulation is a low input technology of improving the nutrient status of tropical soils for sustainable crop production. It combines the attributes of both organic and inorganic fertilizers (Ayeni, 2008). The increase in soil OC content caused by the NSBF can be as a result of the carbon supplied to the soil from its huge organic base. Continuous mineralization of organic carbon both from the fertilizer and those native to the soil is however expected due to ready supply of nutrients from the mineral fraction of the organomineral formulation. Application of mineral fertilizer to soils has been found to increase the rate of organic matter mineralization, leading to a decrease in the content of easily decomposable organic matter in the soil that is related to a decrease in microbial population (Collins et al., 1992, Lovell et al., 1995). Increase in soil OC is not significant because there was no room for accumulation of organic carbon. The higher level of OC in jars treated with nicosulfuron at the initial stage of the experiment was probably due to accumulation of organic carbon in the jar as a result of suppression of microbial activities by the herbicide. This inhibitory effect of the herbicide also reflected in the status of the soil carbon mineralization quotient (qM), which was low at the beginning of incubation but later increased as incubation progressed. OC concentration of the soil decreased at these stages of incubation because microbial activity increased, and this activity appeared to increase with increased herbicide concentration.

Application of the fertilizer in the absence of herbicide retained more OC in the soil. This indicates that nicosulfuron presumably forms a synergy with the organomineral formulation to increase CO_2 emission – a situation that is inimical to soil carbon sequestration. This was further validated with nicosulfuron increasing CO_2-C production compared to the fertilizer treatment alone. The increase in soil carbon mineralization quotient recorded with the application of neem cake formulation is associated with the herbicide that caused more carbon mineralization to happen compared to the unfertilized soil. Increase in soil carbon mineralization quotient can be attributed to increase in soil carbon content provided by the addition of fertilizer (Gomez et al., 2006). The reduction caused by the herbicide to the parameter can be connected to the repressive impact of the herbicide on the soil microbial activities (Šantrić et al., 2014). The increase in soil pH as a result of the addition of the neem seed cake formulation may be due to inhibition of nitrification. Neem cake has been reported to inhibit nitrification, a process which has been implicated for soil acidification owing to its potential to increase H^+ concentration of the soil (Brady and Weil, 2008). It has been proposed that replacing chemical fertilizer with organic fertilizer of appropriate amount according to the need of the crop is a good measure to buffer soil acidification (Wang et al., 2010).

Conclusions

The two rates of nicosulfuron tested in this study caused repression on the soil microbial activity as measured by soil carbon mineralization. However, addition of the neem seed-based fertilizer- an organomineral formulation reversed the inhibition. This indicates that the fertilizer formulation is suitable as a source of nutrients in soils where nicosulfuron is employed for weed control. Furthermore, the combined effects of the two inputs on both soil respiration and carbon mineralization quotients indicate a synergy that caused carbon to be more rapidly mineralized, a situation that is likely to reduce the carbon sequestration ability of the soil. The study recommends that the neem seed-based fertilizer is a viable bio-stimulant to address nicosulfuron contamination of agricultural soils for effective mineralization of the herbicide.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest.

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