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Evaluating the impact of synthetic herbicides on soil dwelling macrobes and the physical state of soil in an agro-ecosystem

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ABSTRACT

This study evaluated three herbicides active ingredients: Paraquat, Glyphosate and 2,4-D Amine in commercial formulations as Frankoquat, Roundup and Agriherb respectively under field conditions to determine their influence on soil dwelling macrobes and the physical state of soil. Herbicides were serially diluted to three treatment concentrations for each plus three controls. Herbicide concentrations were applied to the demarcated field on three consecutive occasions in splits. Macrobes extraction from soil was done under a stereo microscope at 20 × magnification. The Simpson's diversity index was used to calculate the soil macrobes diversity. Soil water content, bulk density and total porosity of sampled soils were determined. The study revealed that both herbicides and non-herbicides treatment had no statistical significance ($p > 0.05$) on the soil dwelling macrobes. Also, a Simpson's index of diversity, estimated as 53.46%, showed how the experimental area is lowly diverse in the specific soil dwelling macrobes identified. Significant correlations existed between the soil water content, bulk density, total porosity and number of soil macrobes at $p < 0.05$. This level of significance showed in most instances for Frankoquat herbicide concentration treatments as well as Roundup. For Agriherb and control treatments the correlations were present but majority was not significant. In most situations, the soil dwelling macrobes decreased with increasing soil physical conditions. Thus, the dynamics in soil physical properties affected macrobes abundance in soil, with the slightest influence coming from the herbicides concentrations used in the experiment. The study recommended that Frankoquat and Roundup herbicides could be used to control weeds on farmer's field because, their influence were slightly felt on the soil macrobes and also, quite a number soil dwelling macrobes recovered after application.

1. Introduction

Agro-ecosystems are very dynamic as they are highly manipulated by man to the advantage of their cultivated crops. By this, several agronomic practices are put in place during cultivation to maximise yield and reduce losses as much as possible. Most of the agronomic practices, especially those targeted at pest, weed and land preparation for crop cultivation and protection do have adverse effects on the environment, especially on soil macrobes communities (Zhan et al., 2014; Zhu and Zhu, 2015). To mention is conventional tillage practices, which include ploughing and harrowing. This is reported to favour bacterial energy channel in soil food chain where plant residues redistribute (Hendrix et al., 1986). In contrast, no-tillage practice is also reported to favour fungal energy channels through immobilisation of plant residues after decomposition (Hendrix et al., 1986). A conflicting finding to the latter is evident in the work of Petersen (2002). Petersen (2002) reported that conventional ploughing as against inverting tillage reduced Collembolan population in the upper soil stratum compared to the two tillage treatments (combined), which resulted in similar population changes in Collembolan population species found in the whole soil horizon. In a related study, significant reduction in Collembolan population after ploughing is reported with a recovery rate of one year (Liu et al., 2016). From the same study, Acari population also reduced after ploughing, but different trophic groups identified in the study showed different recovery patterns. Thus, decomposer population failed to recover but predaceous mites did recover from its previous population levels (Liu et al., 2016).

As indicated earlier, weed control as a crop management practice aimed to maximise crop yield comes with its own detrimental effects on the soil macrobes communities. In this view, many studies involving

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weed management practices is documented. For example, herbicides such as atrazine and 2,4,-D have been found to have effect on Collembola population, thus, they decreased Collembola diversity significantly (Liu et al., 2016). In a related study, which contradicts the latter; herbicides have been found not to have any significant effect on surface-arthropods but affected Collembola more than Formicidae in the short term (Greenslade et al., 2010). This was attributed to less exposure in surface soil and hydrophobic structures of fauna body (Greenslade et al., 2010).

The effects of agro-chemicals discussed above greatly manipulate the non-target organism communities, most of which are beneficial invertebrates such as pollinators, insect natural enemies and decomposers (Cerejeira et al., 2003; Ntow, 2001; Sattler et al., 2007). Several, of these organism communities, specifically macrobes (Arthropods and Molluscs) and microbes (bacteria and fungi) play important roles in nutrient cycling that occur in the environment. Their feeding and movement activities result in the breakdown of organic matter, which improves both the chemical and physical condition of the soil by releasing and attracting ions from soil into solution for the benefit of crop plants (Bernard et al., 2012; Cock et al., 2012; Coleman and Wall, 2015; Gessner et al., 2010). This directly or indirectly affects major soil processes such as infiltration, deep percolation, which are physical processes and carbonation and hydrolysis, which are chemical processes of soil formation (Basset et al., 2012; Carrillo et al., 2011; Diekötter et al., 2010; García et al., 2010; Kremen et al., 1993). Thus, it is important to conserve these beneficial organisms.

As discussed above these effects of agro-chemicals on non-target organisms and the entire ecosystem is well documented (Cerejeira et al., 2003; Greenslade et al., 2010; Liu et al., 2016; Ntow, 2001; Sattler et al., 2007). However, what we do not know is the specific concentrations of agro-chemicals at which the activities of these soil dwelling macrobes ceases, either through a reduced or increased population. Specifically, those that bore big holes in the soil to form macropores network for air circulation. The pore network created by these soil animals is said to improve soil quality by enhancing aeration in the soil system for plant root respiration. However, as mentioned before the increased use of pesticides and herbicides on agricultural soils, with the quest to control pest and weeds cause soil contamination by leaving residues of toxic elements in the soil after performing it function. When these herbicides and pesticides are applied, the possibility exist that the chemicals may exert certain stresses on non-target organisms, such as soil microbes and macrobes (Greenslade et al., 2010; Lins et al., 2007; Liu et al., 2016; Simon-Sylvester and Fournier, 1979; Wardle and Parkinson, 1990).

Meanwhile, the diversity and abundance of soil dwelling organisms are reducing over the years, according to a review done on risk assessment of agro-chemical use in general (Kattwinkel et al., 2015). This is evident in the reduced prevalence of mushrooms and snails, which hitherto were commonly available even in backyards of villages and peri-urban communities. It is suspected that the excessive use of agrochemicals including herbicides is responsible for this decline. Herbicides may act directly by killing some of these organisms or indirectly by repelling them or removing their preferred food sources. However, the extent and exact influence of specific concentration of these agrochemicals on agro-ecosystems that rely on synthetic chemicals for weed control is not well understood or unclear. Though, soil macrobes population have been shown to be very sensitive to changes in soil conditions (Vasconcellos et al., 2013), soil and agronomic management practices as discussed before (Doblas-Miranda et al., 2008; Maharning et al., 2009; Strickland and Rousk, 2010; Kattwinkel et al., 2015; Liu et al., 2016). On this basis, this research project asked whether (1) different concentrations of common types of herbicide on the market influence the abundance and diversity of soil dwelling macrobes and (2) application of herbicides to the habitat of soil dwelling macrobes affect their population/abundance and physical state of soil. We hypothesed that the application of herbicides at different concentrations onto soil surface to control weeds will not have any impact on the diversity and abundance of soil dwelling macrobes as well as the physical quality of the soil. Our objective was to evaluate the extent to which three different herbicide active ingredients namely, Paraquat, Glyphosate and 2,4-D Amine sold on the Ghanaian market as Frankoquat (FQ), Roundup (RU) and Agriherb (AH) impact on soil dwelling macrobes and the physical state of soil.

2. Materials and methods

2.1. Study area location, demarcation of experimental layout, soil and climate characteristics

The study was carried out at the Biotechnology and Nuclear Agriculture Research Institute (BNARI) research farm (5°40'25''N, 0°12'59''W) of the Ghana Atomic Energy Commission (GAEC), located in the Ga East Municipality of the Greater Accra Region of Ghana. The experiment was carried from July 2014 to October 2014. The experimental field was sited at an area that has not been under cultivation for at least three years with the assumption that three years is a long enough time for the soil ecosystem to regenerate and maintain some level of equilibrium. The area was ploughed and harrowed. Measurements were done to get the experimental design plotted on the field. The dimension for a single experimental plot measured 2.5 m × 3.5 m (8.75 m^2). The total area that contained the individual experimental units was dimensioned 14.5 m × 13.5 m (195.75 m^2). In this total experimental area, twelve units of plots were demarcated on which treatments were assigned for observation. A path of 1.5 m was left between blocks for easy passage.

The soils of the study area belong to the savannah Ochrosols subgroup, which is characterised by very shallow, reddish brown and brown concretionary, medium to light textured soil belying directly over sandstone or quartzite schists (Obeng, 2000). The physical and chemical properties of soils in the study area is described in Table 1, adapted from Frimpong et al. (2011). Rainfall of the study area is reported low and erratic for year 2008 (Frimpong et al., 2011, 2012). Similarly, measurement taken for climatic parameters during the experimental time is shown on Table 2 and this was close to the previous climatic information documented in Frimpong et al. (2011) and Frimpong et al. (2012).

Table 1
Chemical and physical properties of soils at experimental site.

Soil Layer	pH_{H2O}	$C_{organic}$ %	Total N	$P_{average}$ mg/kg	K cmol (+)/kg	Sand %	Silt	Clay	ρ_b kg/m^3
0–20	7.33	1.06	0.36	11.07	0.41	41.4	43.2	15.4	1.34
20–40	7.39	0.50	0.34	6.79	0.30	40.4	44.7	14.9	1.22
40–60	7.83	0.50	0.31	4.28	0.25	45.3	43.8	10.9	1.41
60–80	7.99	0.39	1.26	3.89	0.19	48.0	41.1	11.1	1.33
80–100	7.79	0.36	0.42	2.40	0.21	46.3	43.0	10.7	1.47
100–120	7.85	0.23	1.13	2.10	0.22	55.8	36.4	7.8	1.38