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Effect of glyphosate on soil enzymes and nutrient availability in medium deep black soils

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Abstract
A field experiment of effect of glyphosate on soil enzymes and nutrient availability on medium deep black soils was conducted at STCR farm, MPKV, Rahuri during 2019-20. The experiments was laid out in randomized block design with 3 replications and seven treatments *viz*., Absolute control, glyphosate herbicide application @ 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 litre ha^{-1} with three replications. The soil of experimental plot was clay in texture, slightly alkaline in reaction, low in available nitrogen, medium in phosphorus and organic carbon and high in potassium. The soil dehydrogenase enzyme activity in field was significantly higher in glyphosate application @ 0.5 litre ha^{-1} on fallow land and their residual effect in maize crop at 0, 30 and 60 DAA (1.32, 1.50 and 1.82 µg TPF g^{-1} soil hr^{-1} respectively) and 30 and 60 DAS (8.25 and 8.45 µg TPF g^{-1} soil hr^{-1}). The urease enzyme activity was significantly more in 0.5 litre ha^{-1} on fallow land and their residual effect in maize crop at 0, 30 and 60 DAA and 30 and 60 DAS (95.23, 84.25 and 75.23 µg NH_4-N g^{-1} soil hr^{-1} and 49.73 and 50.23 µg NH_4-N g^{-1} soil hr^{-1} respectively and on par with 1.0, 1.5 and 2.0 litre ha^{-1} respectively). The acid phosphatase enzyme activity was the highest in 0.5 litre ha^{-1} glyphosate application on fallow and their residual effect in maize crop at 0, 30, 60 DAA and 30 and 60 DAS (21.97, 16.73 and 16.93 µg PNP g^{-1} soil hr^{-1} and 29.50 and 32.47 µg PNP g^{-1} soil hr^{-1} respectively) and also for alkaline phosphatase enzyme activity (26.90, 33.80 and 29.33 µg PNP g^{-1} soil hr^{1} and 20.10 and 25.83 µg PNP g^{-1} soil hr^{-1} respectively). The residual soil organic carbon was slightly increased in glyphosate application @ 0.5, 1.0, 1.5 and 2.0 litre ha^{-1} (0.62, 0.65, 0.61 and 0.59% respectively). The residual soil available nitrogen, phosphorus and potassium significantly more in glyphosate application @ 0.5 litre ha^{-1} (263.42, 10.85 and 464.0 kg ha^{-1} respectively). It was on par with 1.0, 1.5 and 2.0 litre ha^{-1} glyphosate application for soil available phosphorus and potassium. The least soil available nitrogen, phosphorus and potassium was in 2.5 litre ha^{-1} glyphosate application (200.70, 9.05 and 442.35 kg ha^{-1} respectively) followed by 3.0 litre ha^{-1} (203.84, 9.25 and 445.15 kg ha^{-1} respectively).

Keywords: glyphosate, soil enzymes, dehydrogenase, urease, phosphatase, residual fertility

Introduction
The sustainable agriculture involves optimizing agricultural resources and at the same time maintaining the quality of environment and sustaining natural resources. The increased use of pesticides in agricultural soils causes the contamination of the soil with toxic chemicals. These chemicals may exert certain effects on non target organisms, soil enzymes, nutrient cycle etc. During last few decades, a large number of herbicides have been introduced as pre and post emergent weed killer in many countries. As farmers continue to realize the usefulness of herbicides, larger quantities are applied to the soils.
Glyphosate (N-(phosphonomethyl) glycine) is the active components of the worldwide most heavily used herbicide (Benbrook, 2016) [1]. It is characterized by high efficiency and low production costs. As a non selective herbicide, glyphosate has the potential to affect a broad spectrum of the plants (Krieger, 2001) [2]. Once absorbed in the foliar tissues, glyphosate will move through the phloem and translocate in the meristem. Glyphosate disrupt the shikimate pathway (phenylanine, tyrosine and tryptophan) which are precursors of vital plant products involved in growth, development, reproduction, defence and environmental response (Maeda and Duduvera, 2012) [3]. The fate pathway of glyphosate in soil are mineralization, immobilization or leaching (Mamy and Barriuso, 2005) [4]. Degradation of glyphosate into it major metabolic amino-methylphosphonic acid (AMPA), is mainly carried out by microbial mechanisms (Kryuchkova *et al*., 2014) [5]. The half life of glyphosate in soil ranges from few days up to two or three months. After 90 days, it is expected that approximately 40-50% of the glyphosate will be degraded in to AMPA (Gimsing. *et al.*, 2004) [6]. Extensive use of glyphosate may lead to AMPA accumulation in soil, as it is more persistent than glyphosate (Mamy and Barriuso, 2005) [4].

Soil enzyme activity appear as good indicator of soil health. Also the soil enzymes are responsible for carbon cycling and nutrient availability to the crop plants in the field. In modern agriculture the use of herbicide is increasing day by day, however the herbicides are xenobiotic compounds affect the soil biological and biochemical activity and thereby nutrient availability in soil. Any change in the microbial population and activity affect nutrient cycling as well as availability of nutrients, which indirectly affect productivity and other soil function. (Wang *et al*. 2008) [7].

In comparison to other pesticides, glyphosate present strong sorption characteristics, the molecules are sorbed by anion exchange process in the soil minerals and through hydrogen bonds in the organic matter (Veiga *et al*., 2001) [8]. The fate of glyphosate compounds in the soils is becoming increasingly important as a xenobiotic compound and strong sorption capacity, the potential impact of glyphosate in high clay content soil needs to monitor for the soil health and sustainable production. In view of this present investigation are planned to study the effect of glyphosate on soil enzyme and nutrient availability in medium deep black soil.

Material and Methods

A field experiment on "Effect of glyphosate on soil enzymes, microbial population and nutrient availability on medium deep black soils" was conducted at Research Farm on Soil Test Crop Response Correlation Scheme, Mahatma Phule Krishi Vidyapeeth, Rahuri which comes under a hot semi-arid area of the Deccan Plateau of India during the year 2019-20. The soil of the experimental area is grouped under Inceptisol soil order and belongs to *Pather* soil series, comprises member of fine montmorillonite hyperthermic family of *Vertic Haplustepts* having clay in texture, slightly alkaline in reaction (7.68), low in available nitrogen (273 kg ha^{-1}), medium in available phosphorus (12.3 kg ha^{1}) and organic carbon (0.57%) and high in available potassium content (448 kg ha^{-1}).

The field experiments was laid out in randomized block design comprising 3 replications and 7 treatments of glyphosate soil application *viz*., Absolute control, glyphosate @ 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 litre ha^{-1} with three replications. Glycel (41% S.L Glyphosate) was applied in the fallow field and representative soil sample were taken for 0, 30 and 60 days after application of herbicide. Thereafter maize crop was sown in the field as a test crop on 60 days after application (DAA) of glyphosate and soil sampling was done at 30 and 60 days after sowing (DAS) i.e 90 and 120 days after application of glyphosate). The periodical samples were immediately analyzed in the laboratory for the soil enzyme activity, soil microbial population and available nutrient content. Standard methods were used for the soil sample analysis. Colorimetric estimation of soil dehydrogenase, acid and alkaline phosphatase enzyme activity as described by Casida *et al.* (1964) [9] and soil urease enzyme activity as described by Tabatabai and Bremmer (1972). Soil available Nitrogen by Alkaline permanganate method (Subbiah and Asija, 1956) [10], Soil available Phosphorus by colorimetric method using 0.5 M $NaHCO_3$ (pH 8.5) as an extractant as described by Olsen *et al*, (1954), [11] Soil available Potassium by Flame photometric method using NH_4OAc as an extractant as described by Jackson (1973) [12].

Results and Discussion

Effect of Glyphosate on Soil Enzyme Activity

Soil Dehydrogenase Enzyme Activity: The effect of graded levels of glyphosate at 0, 30 and 60 days after application (DAA) on fallow land and 30 and 60 days after sowing (DAS) of maize crop on soil dehydrogenase enzyme activity was found significant (Table 1). The soil dehydrogenase enzyme activity was decreased with an increased levels of glyphosate. The glyphosate application @ 3.0 litre ha^{-1} recorded significantly less soil dehydrogenase enzyme activity in fallow land (0.90, 0.40 and 0.50 µg TPF g^{-1} soil hr^{-1} at 0, 30 and 60 DAA respectively) and statistically on par with glyphosate application @ 2.5 litre ha^{-1} (1.08, 0.42 and 0.42 µg TPF g^{-1} soil hr^{-1} at 0, 30 and 60 DAA respectively). The glyphosate application @ 0.5 litre ha^{-1} recorded significantly higher values of soil dehydrogenase enzyme activity (1.32, 1.50 and 1.82 µg TPF g^{-1} soil hr^{-1} at 0, 30 and 60 DAA respectively) in fallow land. The treatment of residual effect of glyphosate application @ 1.0 litre ha^{-1} recorded significantly higher soil dehydrogenase enzyme activity at 30 and 60 days after sowing in maize (9.80 and 9.75 µg TPF g^{-1} soil hr^{-1}). Whereas, it was statistically on par with each other with glyphosate application @ 1.5, 2.0, 2.5 and 3.0 litre ha^{-1} at 30 days after sowing (9.02, 8.38, 8.35 and 8.35 µg g^{-1} soil hr^{-1} respectively). Thus, the application of glyphosate in fallow land considerably affected upto 60 days after application. It was increased on the same land at 30 and 60 days after sowing of maize crop. Initially, the glyphosate was degraded by the soil microorganisms in fallow land upto 60 days after application. Thereafter, the maize crop was sown with addition of recommended dose of fertilizers. The glyphosate adsorption was inhibited by the addition of phosphorus to soil (Hance, 1976) [14]. This leads to degradation of glyphosate by microbial activity. This might be the reason that the increased soil dehydrogenase activity at 30 and 60 days after sowing of maize crop.

Soil Urease Enzyme Activity: The soil urease enzyme activity as influenced by levels of glyphosate application in fallow land and their residual effect in maize crop are presented in Table 2. The soil urease enzyme activity was significantly higher in glyphosate application @ 0.5 litre ha^{-1} days after application (DAA) (95.23 and 84.25 µg NH_4-N g^{-1} soil hr^{-1} at 0 and 30) and statistically on par with glyphosate application @ 1.0 litre ha^{-1} (92.73 and 82.73 µg NH_4-N g^{-1} soil hr^{-1} at 0 and 30). However, glyphosate application @ 2.5 and 3.0 litre ha^{-1} recorded significantly lower values of soil urease enzyme activity at 30 and 60 days after application in fallow land. The least soil urease enzyme activity was noticed in glyphosate application @ 3.0 litre ha^{-1} at 30 and 60 days after sowing (39.73 and 36.73 µg NH_4-N g^{-1} soil hr^{-1}). The reduced soil urease enzyme activity at higher doses of glyphosate might be because of inhibiting proliferation of soil microbial population.

Table 1: Effect of glyphosate on soil dehydrogenase enzyme activity in Inceptisol

Tr. No.	Treatment	Soil dehydrogenase enzyme activity (µg TPF g^{-1} soil hr^{-1})				
		Fallow			Maize Sowing	
		0 days	30 DAA	60 DAA	30 DAS	60 DAS
T_1	Absolute control	1.07	0.77	1.32	8.65	9.17
T_2	Glyphosate @ 0.5 litre ha^{-1}	1.32	1.50	1.82	8.25	8.45
T_3	Glyphosate @ 1.0 litre ha^{-1}	0.95	0.90	1.02	9.80	9.75
T_4	Glyphosate @ 1.5 litre ha^{-1}	1.00	0.75	1.00	9.02	9.55
T_5	Glyphosate @ 2.0 litre ha^{-1}	1.05	0.70	0.95	8.38	8.60
T_6	Glyphosate @ 2.5 litre ha^{-1}	1.08	0.42	0.42	8.35	8.02
T_7	Glyphosate @ 3.0 litre ha^{-1}	0.90	0.40	0.50	8.35	8.05
	S.E. ±	0.21	0.07	0.04	0.15	0.12
	C.D. at 5%	0.66	0.22	0.15	0.46	0.40

Table 2: Effect of glyphosate on soil urease enzyme activity in Inceptisol

Tr. No.	Treatment	Soil urease enzyme activity (µg NH_4-N g^{-1} soil hr^{-1})				
		Fallow			Maize Sowing	
		0 days	30 DAA	60 DAA	30 DAS	60 DAS
T_1	Absolute control	103.2	113.7	87.50	47.23	36.73
T_2	Glyphosate @ 0.5 litre ha^{-1}	95.23	84.25	75.23	49.73	50.23
T_3	Glyphosate @ 1.0 litre ha^{-1}	92.73	82.73	64.73	42.73	43.23
T_4	Glyphosate @ 1.5 litre ha^{-1}	88.73	79.23	61.73	40.40	44.73
T_5	Glyphosate @ 2.0 litre ha^{-1}	83.00	75.23	69.23	40.23	39.73
T_6	Glyphosate @ 2.5 litre ha^{-1}	82.73	71.73	57.73	43.73	44.73
T_7	Glyphosate @ 3.0 litre ha^{-1}	80.23	64.73	53.00	39.73	36.73
	S.E. ±	1.30	0.98	0.96	0.95	0.55
	C.D. at 5%	4.01	3.03	2.96	2.95	1.70

Soil Acid Phosphatase Enzyme Activity

The soil acid phosphatase enzyme activity was significantly influenced by levels of glyphosate application in fallow land and their residual effect in maize crop (Table 3). The soil acid phosphatase enzyme activity was decreased with increased levels of glyphosate application at 30 and 60 days after application in fallow land. It was the least in treatment glyphosate application @ 3.0 litre ha^{-1} at 30 and 60 days after application (16.13 and 12.20 µg PNP g^{-1} soil hr^{-1}). However, it was statistically at par with glyphosate application @ 1.5, 2.0 and 2.5 litre ha^{-1}. The glyphosate application @ 0.5 and 1.0 litre ha^{-1} are statistically on par with each other for the acid phosphatase enzyme activity at 30 and 60 days after application. The results revealed that the glyphosate application @ 0.5 or 1.0 litre ha^{-1} has less adverse effect on soil acid phosphatase enzyme activity upto 60 days after application in fallow land than the rest of treatments of glyphosate application. The residual effect of glyphosate application in maize crop was significantly influenced the soil acid phosphatase enzyme activity at 30 and 60 days after sowing. However, residual effects of various levels of glyphosate application were found statistically on par with each other for their soil acid phosphatase enzyme activity at 30 and 60 days after sowing. The higher doses of glyphosate in fallow land decrease the acid phosphatase enzyme activity. The residual effect of glyphosate in maize crop not affected the soil acid phosphatase enzyme activity.

Table 3: Effect of glyphosate on soil acid phosphatase enzyme activity in Inceptisol

Tr. No.	Treatment	Soil acid phosphatase enzyme activity (µg PNP g^{-1} soil hr^{-1})				
		Fallow			Maize Sowing	
		0 days	30 DAA	60 DAA	30 DAS	60 DAS
T_1	Absolute control	18.03	15.53	17.20	26.67	21.40
T_2	Glyphosate @ 0.5 litre ha^{-1}	21.97	16.73	16.93	29.50	32.47
T_3	Glyphosate @ 1.0 litre ha^{-1}	23.50	18.83	18.00	26.40	31.53
T_4	Glyphosate @ 1.5 litre ha^{-1}	22.23	16.60	16.23	27.00	31.17
T_5	Glyphosate @ 2.0 litre ha^{-1}	20.14	15.93	15.70	27.50	30.70
T_6	Glyphosate @ 2.5 litre ha^{-1}	20.33	16.03	13.40	27.17	34.83
T_7	Glyphosate @ 3.0 litre ha^{-1}	18.00	16.13	12.20	28.70	33.93
	S.E. ±	0.87	0.32	0.54	0.90	1.63
	C.D. at 5%	2.68	0.99	1.68	2.85	5.04

Soil Alkaline Phosphatase Enzyme: The soil alkaline phosphatase enzyme activity at 0, 30 and 60 days after application (DAA) in fallow land and their residual effect in maize crop at 30 and 60 days after sowing (DAS) were significantly influenced by the graded levels of glyphosate application (Table 4). The soil alkaline phosphatase enzyme activity was decreased with increased levels of glyphosate application in fallow land and their residual effect in maize crop. The highest activity of alkaline phosphatase enzyme at 30 and 60 days after application in fallow land was found in treatment glyphosate application @ 1.0 litre ha^{-1} (36.90 and 32.20 µg PNP g^{-1} soil hr^{-1}) and statistically on par with glyphosate application @ 0.5 litre ha^{-1} (33.80 and 29.33 µg PNP g^{-1} soil hr^{-1}). The residual effect of glyphosate application @ 1.0 litre ha^{-1} in maize crop recorded significantly higher soil alkaline phosphatase enzyme activity at 30 and 60 days after sowing (24.07 and 29.10 µg PNP g^{-1} soil hr^{-1}) and statistically on par with residual effect of glyphosate application @ 0.5 litre ha^{-1} at 60 days after sowing (25.83 µg PNP g^{-1} soil hr^{-1}). However, the rest of treatments showed the similar trend as that of in glyphosate application in fallow land.

Table 4: Effect of glyphosate on soil alkaline phosphatase enzyme activity in field

Tr. No.	Treatment	Soil alkaline phosphatase (µg PNP g^{-1} soil hr^{-1})				
		Fallow			Maize Sowing	
		0 days	30 DAA	60 DAA	30 DAS	60 DAS
T_1	Absolute control	17.93	40.33	42.50	28.97	18.30
T_2	Glyphosate @ 0.5 litre ha^{-1}	26.90	33.80	29.33	20.10	25.83
T_3	Glyphosate @ 1.0 litre ha^{-1}	10.63	36.90	32.20	24.07	29.10
T_4	Glyphosate @ 1.5 litre ha^{-1}	11.90	31.50	21.13	22.97	22.02
T_5	Glyphosate @ 2.0 litre ha^{-1}	7.80	31.40	28.53	21.73	28.50
T_6	Glyphosate @ 2.5 litre ha^{-1}	4.43	30.63	22.83	22.27	27.33
T_7	Glyphosate @ 3.0 litre ha^{-1}	8.20	31.03	24.13	16.90	22.27
	S.E. ±	0.89	1.37	0.97	0.91	1.16
	C.D. at 5%	2.75	4.23	2.99	2.81	3.60

Effect of Glyphosate on Residual Soil Fertility

Soil Organic Carbon: The soil organic carbon was significantly influenced by the glyphosate application and their residual effect in maize crop (Table 5). The soil organic carbon in treatment residual effect of glyphosate @ 1.0 litre ha^{-1} was recorded significantly higher value (0.65%). However, it was statistically on par with the treatment 0.5 and 1.5 litre ha^{-1} residual effect of glyphosate (0.62 and 0.61%). The higher values of organic carbon might be associated with the lower doses of glyphosate in fallow land controlled the less weed as compared to higher doses of glyphosate. The root biomass of weed add the organic matter in soil. Similarly, in maize sown crop the addition of root biomass of maize crop also added in soil, good soil microbes root interface increased the microbial population and cumulative effective these increased soil organic carbon in soil. Whereas, the higher doses of glyphosate in fallow land and their residual effect in maize crop controlled the weed in both the situation and decreased microbial population. Hence, the less organic carbon in soil as according with (Baboo *et al.* 2013) [13] who reported there was significant reduction in organic carbon with time. Herbicide treatments resulted an initial increase upto 14th days followed by significant drop in microbial biomass-C. The gradual increase in microbial counts may be attributed to their ability to temporarily mineralize and use herbicide as the energy source. Thus, the application of glyphosate @ 0.5, 1.0 and 1.5 litre ha^{-1} in fallow land and their residual effect in maize was found beneficial for soil organic carbon at harvest than the higher doses of glyphosate.

Soil Available Nitrogen: The soil available nitrogen was significantly influenced by the glyphosate application and their residual effect in maize crop (Table 5). The soil available nitrogen content was significantly higher in treatment glyphosate application @ 0.5 litre ha^{-1} on fallow land with its residual effect in maize crop at harvest (263.42 kg ha^{-1}). It was closely followed by glyphosate application @ 1.0 litre ha^{-1} on fallow land and its residual effect in maize at harvest (247.74 kg ha^{-1}). The glyphosate application @ 2.5 and 3.0 litre ha^{-1} on fallow land and their residual effect in maize crop at harvest was recorded significantly less values of soil available nitrogen but statistically on par with each other (200.70 and 200.70 kg ha^{-1}). In general, lower doses of glyphosate application i.e. 0.5 and 1.0 litre ha^{-1} are beneficial for soil available nitrogen and higher doses adversely affect the soil available nitrogen. The higher values of soil available nitrogen in lower doses of glyphosate application mainly due the less adverse effect on soil organic carbon content and microbial population, which are responsible for transformation of organic form of soil nitrogen to inorganic form. Devi *et al*. (2013) [15] reported that application of herbicides did not affect the chemical properties of lateritic soil, when they were applied at recommended levels. Whereas, higher doses adversely affected the soil organic carbon, microbial population and soil pH decreased the soil available nitrogen.

Soil Available Phosphorus: The soil available phosphorus was significantly influenced by the glyphosate application and their residual effect in maize crop (Table 5). The glyphosate application @ 0.5 litre ha^{-1} on fallow land and its residual effect in maize crop was recorded significantly higher values of soil available phosphorus at harvest of maize (10.85 kg ha^{-1}) and statistically on par with 1.0, 1.5 and 2.0 litre ha^{-1} (10.75, 10.30 and 10.60 kg ha^{-1} respectively). Whereas, it was significantly less in glyphosate application @ 2.5 and 3.0 litre ha^{-1} (9.05 and 9.25 kg ha^{-1}). However, the treatments of glyphosate application recorded less values of soil available phosphorus than the initial content of soil available phosphorus (12.30 kg ha^{-1}). This might be because of adsorption of added phosphorus on clay complex. Similarly, the less microbial activity requires for transformation of soil phosphorus in available form. The results revealed that the lower doses of glyphosate in fallow land and their residual effect in maize crop are beneficial for soil available phosphorus upto 2.0 litre ha^{-1} glyphosate and adverse effect due to 2.5 and 3.0 litre ha^{-1}. In general, glyphosate application upto 2.0 litre ha^{-1} in fallow land and its residual effect in maize crop did not influenced the soil available phosphorus.

Soil Available Potassium: The soil available potassium was significantly influenced by the glyphosate application and 0their residual effect in maize crop (Table 5). The soil available potassium at harvest of maize was significantly influenced due to the glyphosate application in fallow land and their residual effect in maize crop. The glyphosate application @ 0.5, 1.0 and 1.5 litre ha^{-1} in fallow land and its residual effect in maize crop was found statistically on par with each other and significantly superior over rest of the treatments (464.0, 461.45 and 460.60 kg ha^{-1} respectively). The glyphosate application @ 2.0, 2.5 and 3.0 litre ha^{-1} in fallow land and their residual effect in maize were recorded less values of soil available potassium at harvest of maize (450.70, 442.35 and 445.15 kg ha^{-1} respectively). The results revealed that the glyphosate application upto 1.5 litre ha^{-1} did not influenced the soil available potassium.

Table 5: Effect of glyphosate on soil organic carbon, pH and available nutrient content after harvest of maize.

Tr. No.	Treatment	Organic carbon (%)	Soil Av N (kg ha^{1})	Soil Av P (kg ha^{1})	Soil Av K (kg ha^{1})
T_1	Absolute control	0.59	246.18	8.05	436.80
T_2	Glyphosate @ 0.5 litre ha^{-1}	0.62	263.42	10.85	464.00
T_3	Glyphosate @ 1.0 litre ha^{-1}	0.65	247.74	10.75	461.45
T_4	Glyphosate @ 1.5 litre ha^{-1}	0.61	216.28	10.30	460.60
T_5	Glyphosate @ 2.0 litre ha^{-1}	0.59	210.11	10.60	450.70
T_6	Glyphosate @ 2.5 litre ha^{-1}	0.53	200.70	9.05	442.35
T_7	Glyphosate @ 3.0 litre ha^{-1}	0.53	203.84	9.25	445.15
	Initial	0.57	273.00	12.3	448
	S.E. ±	0.015	2.13	0.25	4.326
	C.D. at 5%	0.047	6.57	0.78	13.33

Conclusion

It is concluded from the results the glyphosate application @ 0.5 litre ha^{-1} on fallow land and their residual effect in maize crop was recorded more soil dehydrogeanse urease, acid and alkaline phosphatase enzyme activity at 0, 30 and 60 DAA in fallow land at 30 and 60 DAS in maize. The residual soil fertility after maize in terms of organic carbon was increased at glyphosate application @ 0.5, 1.0 and 1.5 litre ha^{-1} on fallow land and their residual effect in maize at harvest. These levels of glyphosate application are beneficial for residual soil available nitrogen, phosphorus and potassium.

The application of glyphosate @ 0.5, 1.0 and 1.5 litre ha^{-1} on fallow land and their residual effect in maize crop are beneficial for dehydrogenase urease, acid and alkaline phosphatase enzyme activity and maintaining residual soil fertility.

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