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Enzyme dynamics and organic carbon status of soil as influenced by flucetosulfuron in wet seeded rice

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Abstract

A study was under taken during the *Kharif* and *Rabi* seasons of 2016-'17 in Kalliyoor Panchayat, Nemom block, Thiruvananthapuram district, Kerala, India (8.4455^0 N and 76.9918^0 E) to assess the effect of the herbicide flucetosulfuron on soil enzymes viz., dehydrogenase, acid phosphatase, and urease and organic carbon content of soil under wet seeded system of rice cultivation. The experiment was laid out in Randomised Block Design (RBD) with 12 treatments replicated thrice. Flucetosulfuron @ 20, 25 and 30 g ha^{-1} applied at 2-3, 10-12 and 18-20 days after sowing (DAS) along with two control treatments viz., hand weeding at 20 and 40 DAS and unweeded control comprised the treatments. In the case of dehydrogenase enzyme activity and organic carbon content, at 15 and 30 days after herbicide application, during both the seasons, the dose 25 g ha^{-1} was found to be the best when applied at 10-12 and 18-20 DAS compared to 2-3 DAS. Significant and positive correlation was noticed between dehydrogenase enzyme and organic carbon content of the soil. Acid phosphatase enzyme activity was found to be non-significant at 15 and 30 days after herbicide application, during both the seasons. It was also observed that herbicide application could increase the urease enzyme activity irrespective of dose and time of application, in both the seasons. Overall, the results revealed that none of the major enzymes were harmfully influenced by the sulfonyl urea herbicide, flucetosulfuron at the tested doses and time of application.

Keywords: Acid phosphatase, Dehydrogenase, Flucetosulfuron, Soil enzymes, Soil health, Urease

Introduction

In direct seeded rice (DSR), simultaneous emergence of rice seedlings and weeds causes severe crop-weed competition, resulting in 15- 20 per cent yield loss on an average (Hasanuzzaman et al., 2009), and in severe cases may exceed 50 per cent (Jayadeva et al., 2011). In large scale rice farming, herbicide based weed management has become the smartest and most viable option due to scarcity and high labour wage rate (Singh et al., 2006; Anwar et al., 2012). Among herbicides, use of low dose, high efficacy herbicides (LDHE) is becoming more popular due to its high efficacy and environmental safety. Flucetosulfuron is one of the latest additions to this array, and it is a broad spectrum, systemic herbicide, inhibiting acetolactase synthase (ALS) enzyme, thus causing chlorosis of the plant, leading to death of apical meristems (Paranjape et al., 2014).

There is an increasing concern that herbicides not only affect target organisms (weeds) but also the microbial communities present in the soils, and these non-target effects may reduce the performance of important soil functions (Sebiomo et al., 2011). Soil microbial and earthworm population, soil enzyme activity and organic carbon content in soil are considered as the bio-indicators of soil health because of their active role in soil organic matter production, decomposition of xenobiotics and cycling of nutrients, ease of measurement and rapid response

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to management practices (Raj and Syriac, 2017). According to Gianfreda and Bollang (1996), soil enzyme activities may be affected directly or indirectly by natural and anthropogenic factors. Herbicides are one of the major anthropogenic factors introduced into the soil component pools and are expected to affect the catalytic efficiency and comportment of soil enzymes, which contribute to total biological activity of the soil-plant environment under different situations (Dick, 1997). With this background, the present study was carried out to find out the effect of the sulfonyl urea herbicide, flucetosulfuron on soil enzymes viz., dehydrogenase, acid phosphatase, urease and soil organic carbon, for getting a better understanding of the effect of the herbicide on soil health.

Materials and Methods

Field experiments were conducted during *Kharif* and *Rabi* seasons of 2016-'17 in Kalliyoor Panchayat, Nemom block, Thiruvananthapuram district, Kerala, India (8.4455^0 N and 76.9918^0 E at an altitude of 29 m above MSL). The experimental area experienced a warm, humid, tropical climate. The soil was Typic haplaustalf under the order *Alfisols.* The experiment was laid out in RBD with 12 treatments replicated thrice viz., T_1 : Flucetosulfuron @ 20 g ha^{-1} at 2-3 DAS, T_2 : Flucetosulfuron @ 25 g ha^{-1} at 2-3 DAS, T_3 : Flucetosulfuron @ 30 g ha^{-1} at 2-3 DAS, T_4 : Flucetosulfuron @ 20 g ha^{-1} at 10-12 DAS, T_5 : Flucetosulfuron @ 25 g ha^{-1} at 10-12 DAS, T_6 : Flucetosulfuron @ 30 g ha^{-1} at 10-12 DAS, T_7 : Flucetosulfuron @ 20 g ha^{-1} at 18-20 DAS , T_8 : Flucetosulfuron @ 25 g ha^{-1} at 18-20 DAS , T_9 : Flucetosulfuron @ 30 g ha^{-1} at18-20 DAS, T_{10}: Bispyribac sodium @ 25 g ha^{-1} at 15 DAS, T_{11}: Hand weeding at 20 and 40 DAS and T_{12} : Unweeded control. Short duration rice variety Kanchana (PTB 50) was selected as the test crop which was released from Regional Agricultural Research Station, Pattambi, Kerala. The size of the experimental plot was 5 m x 4 m (gross) and 4.7 m x 3.7 m (net). Herbicides were applied on to the surface of soil using knapsack sprayer with flood jet nozzle (spray volume 500 L ha^{-1}). The crop was fertilized with 70:35:35 kg ha^{-1} N, P and K, with one third N and K and half P applied at 15 DAS, one third N and K and half P applied at 35 DAS, and remaining one third N and K applied at 55 DAS. Basal dose of organic manure was supplied with well decomposed farm yard manure (FYM) with an analytical value of 0.49, 0.2, and 0.46 per cent N, P_2O_5 and K_2O respectively. At the time of sowing a thin film of water was maintained in the field which was gradually increased to 5 cm at tillering and maintained till 2 weeks before harvest. Just before herbicide application, the field was drained, and reflooded 48 hours after application. Soil samples were taken just before herbicide application and at 15 and 30 days after herbicide application, at a depth of 15 cm, using soil auger. Dehydrogenase activity was measured using the methodology suggested by Casida et al. (1964) *i.e.,* reduction of 2,3,5-triphenyltetrazoliumchloride (TTC) to red-coloured triphenylformazon (TPF), which was determined spectrophotometrically. To estimate acid phosphatase activity, soil was incubated with buffered (pH 6.5) para nitrophenyl phosphate tetrahydrate, and para nitrophenol released was determined and expressed as explained by Evasi and Tabatabai (1977). Urease activity of soil was determined by the method described by Watts and Crisp (1954) and was expressed as µg urea hydrolyzed g^{-1} soil h^{-1}. Rapid titration method (Walkley and Black, 1934) was used for the estimation of soil organic carbon. The data generated from the experiment were statistically analysed using analysis of variance technique (ANOVA) of Randomized Block Design described by Cochran and Cox (1965).

Results and Discussion

Soil dehydrogenase activity: A perusal of data (Table 1) indicated that weed management practices significantly influenced the dehydrogenase enzyme activity. An increasing trend in the enzyme activity could be seen from just before herbicide application

Table 1. Effect of weed management treatments on dehydrogenase activity in soil

Treatments	Dehydrogenase activity (µg TPF g^{-1} soil $24h^{-1}$)					
	Kharif (2016)			Rabi (2016-17)		
	JBHA	15 DAHA	30 DAHA	JBHA	15 DAHA	30 DAHA
T_1-flucetosulfuron @ 20 g ha^{-1} at 2-3 DAS	72.36	194.63	232.69	73.77	252.72	268.52
T_2- flucetosulfuron @ 25 g ha^{-1} ,,	72.43	199.30	241.33	77.35	258.29	267.56
T_3- flucetosulfuron @ 30 g ha^{-1} ,,	73.45	165.52	192.13	76.65	252.15	262.13
T_4- flucetosulfuron @ 20 g ha^{-1} at 10-12 DAS	72.75	242.48	281.32	76.58	286.95	287.91
T_5- flucetosulfuron @ 25 g ha^{-1} ,,	71.80	296.23	290.66	74.34	294.95	299.68
T_6- flucetosulfuron @ 30 g ha^{-1} ,,	72.71	219.20	256.88	76.90	285.29	279.46
T_7- flucetosulfuron @ 20 g ha^{-1} at 18-20 DAS	72.38	238.13	277.48	75.88	285.22	292.26
T_8- flucetosulfuron @ 25 g ha^{-1} ,,	71.54	297.00	276.78	77.10	297.70	291.05
T_9- flucetosulfuron @ 30 g ha^{-1} ,,	72.83	224.12	262.06	76.26	286.57	284.39
T_{10}-bispyribac sodium @ 25g ha^{-1} at 15DAS	72.18	220.60	258.99	75.56	280.68	271.85
T_{11}-hand weeding at 20 and 40 DAS	72.94	198.27	280.61	77.29	286.95	289.32
T_{12}-unweeded control	73.66	114.78	189.57	74.15	218.75	239.41
SEm(±)	1.163	9.393	4.975	0.691	3.198	3.035
CD (0.005)	NS	29.233	15.484	NS	9.954	9.445

JBHA -Just before herbicide application; DAHA -Days after herbicide application; DAS -Days after sowing

to 30 days after herbicide application in both the crop seasons. Analysis of the data on dehydrogenase activity, just before herbicide application, revealed that there was no significant variation among the treatments, during both the crop seasons. Critical analysis of data with respect to dose of application revealed that at 15 and 30 days after herbicide application during *Rabi,* no significant variation was observed among the herbicide doses tested viz., 20, 25 and 30 g ha^{-1}. Similar results that dehydrogenase activity was significantly stimulated by the application of herbicides have been reported by several investigators (Baruah and Mishra1986; Sireesha et al., 2012; Priya et al., 2017). However, during *Kharif,* at 15 days after herbicide application, significant variation in dehydrogenase enzyme activity was observed for the herbicide doses tested. The treatments T_8 and T_5 (25 g ha^{-1}) were found to be on par and significantly superior to the other doses tested viz., 20 and 30 g ha^{-1}. Similarly, at 30 days after herbicide application, dehydrogenase activity was significantly lower in plots with 30 g ha^{-1} when sprayed at 2-3 days. Sireesha et al. (2012) reported that lower levels of herbicide application increased enzyme activity as compared to higher dose of herbicide.

Regarding the time of application, at 15 days after herbicide application, the dehydrogenase enzyme activity was higher when flucetosulfuron was applied at 18-20 DAS or 10-12 DAS, during both the seasons. At 30 days after herbicide application, during both the seasons, higher dehydrogenase enzyme activity was recorded when flucetosulfuron was applied at 10-12 DAS. However, during *Kharif* season, application of flucetosulfuron at 10-12 DAS was found to be on par with its application at 18-20 DAS as well as with hand weeding at 20 and 40 DAS, whereas during *Rabi* season, application at 10-12 DAS was found to be on par with its application at 18-20 DAS only. On the contrary, application of flucetosulfuron at 2-3 DAS, irrespective of dose of application, recorded relatively lower dehydrogenase enzyme activity compared to its application at later stages of crop growth (10-12 and 18-20 DAS) during both the crop seasons, that too at both times of sampling. This might be due to the active crop growth at the later stages as compared to that at 2-3 DAS. The results corroborated the findings of Islam and Borthakur

Table 2. Effect of weed management treatments on grain yield and straw yield

Treatments	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})	
	Kharif (2016)	Rabi (2016-17)	Kharif (2016)	Rabi (2016-17)
T_1-flucetosulfuron @ 20 g ha^{-1} at 2-3 DAS	5.63	7.53	7.20	8.07
T_2- flucetosulfuron @ 25 g ha^{-1} ,,	5.40	7.41	8.20	7.42
T_3- flucetosulfuron @ 30 g ha^{-1} ,,	5.24	7.63	8.00	7.96
T_4- flucetosulfuron @ 20 g ha^{-1} at 10-12 DAS	7.33	8.94	9.23	7.56
T_5- flucetosulfuron @ 25 g ha^{-1} ,,	8.10	8.56	8.13	7.89
T_6- flucetosulfuron @ 30 g ha^{-1} ,,	7.44	8.57	7.53	7.46
T_7- flucetosulfuron @ 20 g ha^{-1} at 18-20 DAS	7.38	8.26	8.57	8.07
T_8- flucetosulfuron @ 25 g ha^{-1} ,,	6.98	8.21	8.50	8.68
T_9- flucetosulfuron @ 30 g ha^{-1} ,,	6.77	8.47	7.87	7.74
T_{10}-bispyribac sodium @25g ha^{-1} at 15DAS	5.86	7.26	9.17	8.21
T_{11}-hand weeding at 20 and 40 DAS	7.95	8.52	8.90	8.18
T_{12}-unweeded control	3.86	3.97	7.90	7.60
SEm(±)	0.202	0.165	0.510	0.380
CD (0.05)	0.630	0.513	NS	NS

DAS- Days after sowing

(2016) who reported that the soil dehydrogenase activity increases as crop growth advances and reaches peak value at the flowering stage of the crop. Unweeded control registered the lowest dehydrogenase enzyme activity in both the seasons, which is in agreement with the findings of Vandana et al. (2012). During *Kharif* 15 DAHA the best treatment (T_8) recorded 61.35 per cent improvement in dehydrogenase activity as compared to unweeded control while during *Rabi,* percentage improvement in dehydrogenase activity was 26.35 per cent as compared to unweeded control. However, at 30 DAHA, compared to unweeded control the percentage increase was 34.78 and 20.11 per cent during *Kharif* and *Rabi* respectively in the case of T_5, which recorded the highest dehydrogenase enzyme activity. Critical appraisal of the data revealed that application of herbicide at 10-12 and 18-20 DAS, during both the crop seasons, resulted in higher percentage increase in dehydrogenase enzyme content when compared to its application at 2-3 DAS.

Organic carbon (OC) content of soil: Critical appraisal of the data

(Table 3) revealed that the weed management practices adopted in the present study significantly influenced the OC content in the soil. No significant variation was observed among weed management practices, just before herbicide application during both the crop seasons. The OC content was found to be increasing from just before herbicide application to 30 days after herbicide application, during both the crop seasons. Similar results were reported by Sebiomo et al. (2011), who obtained an increase in organic matter content from second to sixth week of herbicide treatment. Application of flucetosulfuron @ 25 g ha^{-1} at 10-12 DAS resulted in higher OC content at 15 days after application, during both the crop seasons. At 30 days after herbicide application also flucetosulfuron applied @ 25 g ha^{-1} at 10-12 DAS recorded higher OC content during *Kharif,* but during the *Rabi* season, its application @ 20 g ha^{-1} at 10-12 DAS recorded higher OC content. In general, herbicide application resulted in increased OC content compared to unweeded control irrespective of doses and time of application of flucetosulfuron, and unweeded control recorded the lowest OC content during both the crop seasons. Corroboratory results were reported by Trimurthulu et al. (2015), for the herbicides pendimethalin, oxyfluorfen and pretilachlor and they opined that presence of herbicides in the rhizosphere of plant might have influenced the physiological activities of host plant root system leading to the release of more quanta

Table 3. Effect of weed management treatments on organic carbon content in soil

Treatments	Organic carbon content in soil (per cent)					
	Kharif (2016)			Rabi (2016-17)		
	JBHA	15 DAHA	30 DAHA	JBHA	15 DAHA	30 DAHA
T_1-flucetosulfuron @ 20 g ha^{-1} at 2-3 DAS	0.85	1.08	1.31	0.88	1.11	1.37
T_2- flucetosulfuron @ 25 g ha^{-1} ,,	0.84	1.09	1.23	0.88	1.17	1.51
T_3- flucetosulfuron @ 30 g ha^{-1} ,,	0.84	1.05	1.20	0.87	1.09	1.29
T_4- flucetosulfuron @ 20 g ha^{-1} at 10-12 DAS	0.84	1.21	1.46	0.90	1.27	1.55
T_5- flucetosulfuron @ 25 g ha^{-1} ,,	0.85	1.29	1.54	0.90	1.36	1.53
T_6- flucetosulfuron @ 30 g ha^{-1} ,,	0.84	1.14	1.17	0.89	1.13	1.47
T_7- flucetosulfuron @ 20 g ha^{-1} at 18-20 DAS	0.84	1.26	1.46	0.89	1.17	1.38
T_8- flucetosulfuron @ 25 g ha^{-1} ,,	0.84	1.15	1.38	0.89	1.16	1.46
T_9- flucetosulfuron @ 30 g ha^{-1} ,,	0.85	1.13	1.21	0.90	1.07	1.41
T_{10}-bispyribac sodium @25g ha^{-1} at 15DAS	0.83	1.05	1.23	0.89	1.16	1.37
T_{11}-hand weeding at 20 and 40 DAS	0.85	1.16	1.25	0.91	1.14	1.45
T_{12}-unweeded control	0.83	0.89	0.95	0.88	0.91	0.91
SEm(±)	0.001	0.539	0.116	0.001	0.092	0.134
CD (0.005)	NS	0.191	0.257	NS	0.203	0.295

JBHA – Just before herbicide application
DAHA – Days after herbicide application
DAS- Days after sowing

of exudates, thus indirectly resulting in higher organic carbon level in the rhizosphere.

Correlation of soil organic carbon and dehydrogenase enzyme activity: Correlation analysis of soil OC and dehydrogenase enzyme revealed significant correlations between the variables assayed (12 pairs of observations were taken). At 15 days after herbicide application, OC was strongly related to dehydrogenase during *Kharif* (r=0.823, pd"0.0001) and *Rabi* (r=0.722, pd"0.0001) seasons (Fig 1 and 2 respectively). At 30 days after herbicide

Table 4. Effect of weed management treatments on acid phosphatase activity in soil

Treatments	Acid phosphatase activity (µg para nitro phenol g^{-1} soil h^{-1})					
	Kharif (2016)			Rabi (2016-17)		
	JBHA	15 DAHA	30 DAHA	JBHA	15 DAHA	30 DAHA
T_1-flucetosulfuron @ 20 g ha^{-1} at 2-3 DAS	44.22	30.18	31.94	34.78	31.21	33.85
T_2- flucetosulfuron @ 25 g ha^{-1} ,,	42.45	32.57	33.75	35.18	31.03	30.00
T_3- flucetosulfuron @ 30 g ha^{-1} ,,	43.06	30.88	31.48	41.45	31.45	33.06
T_4- flucetosulfuron @ 20 g ha^{-1} at 10-12 DAS	44.04	29.45	33.36	38.54	27.75	36.66
T_5- flucetosulfuron @ 25 g ha^{-1} ,,	43.26	31.24	37.33	44.69	28.72	43.00
T_6- flucetosulfuron @ 30 g ha^{-1} ,,	43.30	30.21	37.6	42.24	29.63	34.24
T_7- flucetosulfuron @ 20 g ha^{-1} at 18-20 DAS	43.45	29.30	33.00	40.99	25.54	35.36
T_8- flucetosulfuron @ 25 g ha^{-1} ,,	42.98	32.88	34.36	44.05	33.36	38.06
T_9- flucetosulfuron @ 30 g ha^{-1} ,,	43.69	26.30	36.03	41.36	30.45	37.75
T_{10}-bispyribac sodium @25g ha^{-1} at 15DAS	42.73	31.12	34.18	39.33	28.33	35.33
T_{11}-hand weeding at 20 and 40 DAS	42.51	29.42	38.12	42.75	32.12	41.03
T_{12}-unweeded control	43.26	30.82	41.06	43.66	28.42	38.72
SEm(±)	0.911	1.380	1.753	2.226	1.574	2.037
CD (0.005)	NS	NS	NS	NS	NS	NS

JBHA – Just before herbicide application
DAHA – Days after herbicide application
DAS-Days after sowing

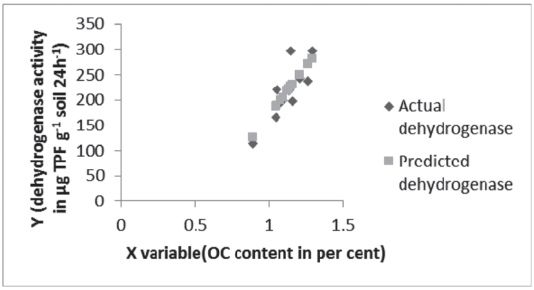

Figure 1. Correlation between dehydrogenase and organic carbon (OC) content of soil at 15 days after herbicide application (*Kharif* 2016)

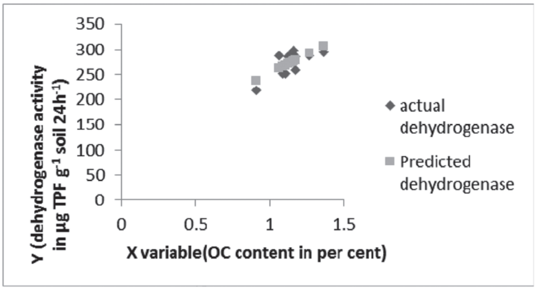

Figure 2. Correlation between dehydrogenase and organic carbon (OC) content of soil at 15 days after herbicide application (*Rabi* 2016

application also, strong relation was found between OC and dehydrogenase enzyme activity during *Kharif* (r=0.765, pd”0.0001) and *Rabi* (r=0.820, pd”0.0001) seasons (Fig 3 and 4 respectively). Islam and Borthakur (2016) also reported that soil OC exhibited significant positive correlations with dehydrogenase activity.

Acid phosphatase activity: The critical evaluation of data (Table 4) on the effect of weed management practices on acid phosphatase activity revealed that weed management practices did not impart any significant influence on this soil enzyme at 15 and 30 days after herbicide application.

Urease activity: The close observation of data (Table 5) revealed that weed management practices could significantly influence the urease enzyme activity in soil at 15 and 30 days after herbicide application. The results revealed that herbicide application could increase the urease enzyme activity irrespective of

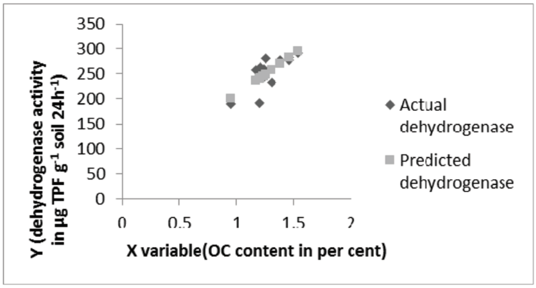

Figure 3. Correlation between dehydrogenase and organic carbon (OC) content of soil at 30 days after herbicide application (*Kharif* 2016)

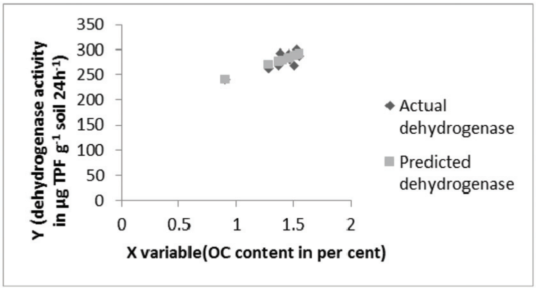

Figure 4. Correlation between dehydrogenase and organic carbon (OC) content of soil at 30 days after herbicide application (*Rabi* 2016-17)

dose and time of application. Just before herbicide application, the enzyme activity was found to be non-significant during both the crop seasons. At 15 days after herbicide application during *Kharif* season, application of flucetosulfuron @ 25 g ha^{-1} at 2-3 DAS recorded higher urease enzyme activity which was found to be on par with its application @ 20 and 30 g ha^{-1} at 2-3 DAS, whereas during *Rabi* season, flucetosulfuron @ 20 g ha^{-1} at 2-3 DAS recorded higher urease enzyme activity which was found to be on par with its application @ 25 and 30 g ha^{-1} at 2-3 DAS and application of flucetosulfuron @ 20, 25 and 30 g ha^{-1} at 18-20 DAS. At 30 days after herbicide application, during *Kharif* season, flucetosulfuron @ 25 g ha^{-1} at 2-3 DAS recorded the highest urease enzyme activity, which was found to be on par with flucetosulfuron @ 20 and 30 g ha^{-1} at 2-3 DAS and flucetosulfuron @ 20 g ha^{-1} at 18-20 DAS. During *Rabi* season, the highest urease enzyme activity was recorded by flucetosulfuron @ 20 g ha^{-1} at 2-3 DAS and was

Table 5. Effect of weed management treatments on urease activity in soil

Treatments	Urease activity (µg urea hydrolysed g^{-1} soil h^{-1})					
	Kharif (2016)			Rabi (2016-17)		
	JBHA	15 DAHA	30 DAHA	JBHA	15 DAHA	30 DAHA
T_1-flucetosulfuron @ 20 g ha^{-1} at 2-3 DAS	116.18	163.49	165.54	115.95	162.71	167.38
T_2- flucetosulfuron @ 25 g ha^{-1} ,,	116.16	164.60	166.54	116.56	160.55	165.38
T_3- flucetosulfuron @ 30 g ha^{-1} ,,	115.30	163.49	165.60	115.79	159.60	165.10
T_4- flucetosulfuron @ 20 g ha^{-1} at 10-12 DAS	116.25	151.11	162.10	115.29	149.77	163.49
T_5- flucetosulfuron @ 25 g ha^{-1} ,,	116.28	151.00	161.99	117.18	150.55	163.55
T_6- flucetosulfuron @ 30 g ha^{-1} ,,	115.79	150.11	161.10	116.73	149.94	162.82
T_7- flucetosulfuron @ 20 g ha^{-1} at 18-20 DAS	116.15	155.10	162.93	116.06	160.10	163.66
T_8- flucetosulfuron @ 25 g ha^{-1} ,,	115.96	160.66	160.77	117.56	158.55	163.38
T_9- flucetosulfuron @ 30 g ha^{-1} ,,	114.63	155.33	161.66	116.79	157.27	162.10
T_{10}-bispyribac sodium @ 25g ha^{-1} at 15 DAS	115.93	147.50	153.11	115.90	137.06	158.05
T_{11}-hand weeding at 20 and 40 DAS	115.74	126.73	151.33	114.90	127.28	154.44
T_{12}-unweeded control	116.49	115.84	150.11	114.23	117.95	152.99
SEm(±)	1.226	0.915	1.288	0.608	3.210	0.767
CD (0.005)	NS	2.847	4.008	NS	9.988	2.387

JBHA – Just before herbicide application
DAHA – Days after herbicide application
DAS-Days after sowing

found to be on par with its application @ 25 and 30 g ha^{-1} at 2-3 DAS. Hand weeding twice and unweeded control recorded lower urease enzyme activity at 15 and 30 days after herbicide application, during both the seasons, indicating the favorable effect of herbicide application on urease activity. During *Kharif*, at 15 DAS the best treatment (T_2) recorded 29.62 and 23.01 per cent improvement as compared to unweeded and hand weeded control, while at 30 DAS percentage improvement in urease activity was 9.87 and 9.13 per cent compared to unweeded and hand weeded control respectively. However, during *Rabi,* at 15 DAS the percentage increase in urease activity was 27.51 and 21.77 per cent respectively, whereas at 30 DAS, 8.60 and 7.73 per cent increase was recorded respectively as compared to unweeded and hand weeded control in the case of T_1, which recorded the highest urease activity at both stages of sampling. This is in agreement with the findings of Baboo et al. (2013) and Tomkiel et al. (2014) who reported enhanced urease activity in herbicide applied soil. Sherene (2017) also reported enhanced urease activity after herbicide application and opined that none of the herbicides had any negative effect on urea hydrolysis even at tenfold increase in the concentration of the herbicide.

Similar result was observed with respect to grain yield (Table 2) also, with herbicide application at 10-12 and 18-20 DAS registering higher grain yield compared to that at 2-3 DAS, irrespective of dose of herbicide used. During *Kharif,* the highest grain yield (8.10 t ha^{-1}) was recorded by flucetosulfuron @ 25 g ha^{-1} at 10-12 DAS which was found to be on par with hand weeding at 20 and 40 DAS. The treatments, flucetosulfuron @ 30 g ha^{-1} at 10-12 DAS, flucetosulfuron @ 20 g ha^{-1} at 18-20 DAS and flucetosulfuron @ 20 g ha^{-1} at 10-12 DAS were found to be on par with hand weeding twice. However, during *Rabi,* flucetosulfuron @ 20 g ha^{-1} at 10-12 DAS recorded the highest grain yield (8.94 t ha^{-1}) and was on par with flucetosulfuron @ 25 and 30 g ha^{-1} at 10-12 DAS, flucetosulfuron @ 30 g ha^{-1} at 18-20 DAS and hand weeding at 20 and 40 DAS. This implies that enhanced enzyme activity in the soil may also have contributed to higher grain yield.

From the present investigation, it can be concluded that the new generation herbicide flucetosulfuron, at the tested doses (20, 25 and 30 g ha^{-1}), and time of application (2-3, 10-12 and 18-20 DAS), is not having any adverse impact on important soil enzymes and soil organic carbon status, the bio-indicators of soil health, implying that it is safe to the soil environment.

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