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Impact of diverse weed management strategies on soil microbial population dynamics in maize

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Abstract
Field experiment was conducted at Eastern block farm, Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore during 2018-19 and 2019-20 to evaluate different weed management practices on soil microbial dynamics in maize. Experiment was laid out in randomized completely block design with three replications and ten treatments comprised of pre emergence atrazine *fb* (followed by) hand weeding at 20 DAS, pre emergence atrazine *fb* power weeder at 20 DAS, pre emergence atrazine at + pendimethalin at (tank mix), pre emergence atrazine + pendimethalin (tank mix) *fb* hand weeding at 20 DAS, early post emergence topramezone at 20 DAS, pre emergence atrazine *fb* early post emergence topramezone at 20 DAS, early post emergence tembotrione at 20 DAS, pre emergence atrazine *fb* early post emergence tembotrione at 20 DAS, hand weeding twice at 20 and 45 DAS and control. Maize was raised during *kharif* season of 2018 and 2019 followed by the residual crop of sunflower in *rabi* season of 2018-19 and 2019-20. The crops were raised under irrigated conditions. The results shown that microbial population was significantly lower in pre emergence atrazine *fb* either early post emergence topramezone at 20 DAS or early post emergence tembotrione at 20 DAS from 3 DAS to 60 DAS, later the microflora started increasing, but it was lesser than control. Unweeded control did not affect the soil microflora from initial to harvest stage of the maize crop.

Keywords: Herbicide, soil microbial population and maize

Introduction
Corn (*Zea mays* L.), often considered the "queen of cereals," holds a pivotal role in global agriculture, serving as a crucial grain for both human consumption and livestock feed. In the face of shifting climate conditions, enhancing and preserving soil health becomes paramount to sustain agricultural production, crucial for securing India's food and nutritional stability. Among the various factors influencing lower maize yields, weeds emerge as the predominant factor, competing with the crop for essential resources such as nutrients, water, sunlight and space. Studies have shown that the reduction in maize grain yield ranges from 33 to 50 percent, varying according to the type of weed species present in the standing crop (Hawaldar and Agasimani, 2012) [1].

Increased weed growth can be attributed to factors such as wide spacing, intensive input usage and the initial slow growth of maize plants. In earlier times, before the advent of synthetic chemicals, weed control relied on methods such as manual weeding, crop rotation, polyculture and other low-input yet sustainable management practices. With the discovery of synthetic herbicides in the early 1930s led to a transition in control methods towards high-input and target-oriented approaches. The scarcity of labor in agriculture is increasingly evident, with availability often delayed and costs prohibitive. Herbicide usage presents a viable alternative to manual weeding. In India, the widespread recommendation for weed control in maize has predominantly focused on the pre-emergence application of atrazine or pendimethalin. The management of weeds that emerge 15-25 days after crop planting is crucial as they compete severely for growth resources, thereby reducing maize productivity. Therefore, there is a need to explore post-emergence herbicides that do not leave residual effects, as they offer greater practicality in the field. Despite the economic benefits, herbicides can also have negative impacts on the soil environment (Fang *et al*., 2015; Pereria *et al*., 2009) [2-3].

Once herbicides penetrate the soil, they can affect the soil environment through processes such as sorption-desorption, transformation, transportation to groundwater and degradation (Chowdary *et al*., 2008) [4]. Therefore, assessing the impact of herbicides on microbial count which are commonly used as indicators of soil fertility and health (Zang *et al*., 2010) [5] is essential for the prudent utilization of herbicides.

Microorganisms are pivotal in the cycling of nutrients and the flow of energy within soil ecosystems, serving as significant indicators of soil health, pollution and ecological restoration (Wu *et al*., 2016; Liu *et al*., 2013) [6-7]. The application of herbicides can lead to inhibition, activation, or no discernible effects on soil microorganisms. According to Xu *et al*., (2017) [8] sterane initially reduced both the diversity and abundance of soil bacteria in a maize field 10 days after application, but these metrics increased after 60 days. Field-level doses of herbicides typically pose minimal risk to soil microbes; however, predicting their response to herbicide application across all environments is challenging. This unpredictability arises from the complex interaction between herbicides and microbes, which is influenced not only by the molecular structure of the herbicide but also by various soil and climatic factors such as temperature, soil moisture and acidity (Tyagi *et al*., 2018) [9]. Therefore, this current study aims to investigate the impact of various herbicidal treatments on soil microflora in maize crop.

Material and Methods

The field experiment was conducted at Tamil Nadu Agricultural University of Agricultural College and Research Institute, Coimbatore in 2018-2019 and 2019-2020. Maize used in the experiment was laid out in randomized block design with three replications consisting of ten treatments *viz*., PE (Pre emergence) Atrazine 50% WP *fb* (followed by) HW (Hand weeding) at 20 DAS, PE Atrazine 50% WP *fb* PW (Power weeding) at 20 DAS, PE Atrazine 50% WP + Pendimethalin 30% EC (Tank mix), PE Atrazine 50% WP + Pendimethalin 30% EC *fb* HW at 20 DAS, EPOE (Early post emergence) Topramezone 33.6% SC at 20 DAS, PE Atrazine 50% WP *fb* EPOE Topramezone 33.6% SC at 20 DAS, EPOE Tembotrione 42% SC at 20 DAS, PE Atrazine 50% WP *fb* EPOE Tembotrione 42% SC at 20 DAS, Hand weeding twice at 20 and 45 DAS and Control. The herbicides as per the treatment schedule were applied as pre - emergence at 1 DAS and post emergence at 20 DAS. Maize crop was fertilized with 250 kg N ha^{-1}, 75 kg P_2O_5 ha^{-1} and 75 kg K_2O ha^{-1}, respectively. Nitrogen was applied in three splits. 25 per cent nitrogen and full dose of phosphorus and potassium were given as basal dose along with ZnSO4 @ 37.5 kg ha-1. Remaining 50 per cent of nitrogen and 25 per cent of nitrogen was top dressed at 25 and 45 DAS respectively. Excluding the weed management practice, all the recommended improved package of practices of maize was followed in this experiment including the general plant protection measures.

The methods employed for analyzing the microbial properties from the experimental plots were collected from the space between the rows at a depth up to 0-15 cm on different dates *viz*., initial (pre- treatment), 0, 3, 15, 30, 60 and 90 day after Sowing (DAS). The soil samples from different replicates for the same weed control treatment were pooled together and then composite soil samples of each herbicidal treatment were taken for microbial analysis by using dilution plate technique following standard methods. Soil dilutions were prepared in sterile distilled water by constant shaking and plating was done separately in replicates in specific media like for bacteria-Nutrient agar medium (Collins *et al*., 2004) [10] at 10^{-6} dilutions, for fungi-Martin'rose bengal streptomycin agar medium (Martin, 1950) [11] at 10^{-4} dilutions and for actinomycetes- Khenheights (Kenknight and munice, 1939) [12] at 10^{-5} dilutions. The petri plates were incubated at 30 °C, 2 days, 4 days and 7 days for bacteria, fungi and actinomycetes respectively. After incubation time, emerged colonies were developed and the viable count of soil microbes was enumerated by following the given formula and expressed as CFU per gram of soil (Colony forming unit).

$$\text{Colony forming unit per ml of sample} = \frac{\text{No.of colonies}}{\text{quantity of sample}} \times \text{Dilution factor}$$

Results and Discussion

Effect of treatments on soil microbes

The experimental results revealed that when the PE and EPOE applied, significant detrimental effect on soil bacteria, fungi and actinomycetes population registering a reduced microbial count up to 30 DAHA (days after herbicide application). Thereafter, microbial activity started to recover slowly. In the plots not receiving the herbicides such as hand weeded, power weeder weeding and unweeded control, the microbial density increased continuously. PE and EPOE herbicides applied at 1 DAS and 20 DAS respectively. Microbial population was estimated in the soil at 0, 3, 15, 30, 60 and 90 DAS of maize.

Soil bacteria

Bacterial population was significantly influenced by weed control methods. During initial stages, no marked variations among the treatments were noticed (Table 1). Hand weeding twice at 20 and 45 DAS (T_9) and Unweeded control (T_{10}) significantly recorded higher bacterial population at all stages of observation. This was on par with EPOE tembotrione (T_7) and EPOE topramezone (T_5) at 3 and 15 DAS. Application of PE atrazine *fb* HW at 20 DAS (T_1), PE atrazine *fb* power weeder at 20 DAS (T_2), PE atrazine + pendimethalin (tank mix) *fb* HW at 20 DAS (T_4) and PE atrazine + pendimethalin (tank mix) (T_3) were on par with T_{10} at 60 and 90 DAS.

Table 1: Effect of different treatments on population of bacteria in soil (Pooled data of 2018-19 and 2019-20)

Treatments	0 DAS	3 DAS	15 DAS	30 DAS	60 DAS	90 DAS
T_1: PE atrazine at 0.5 kg ha^{-1} *fb* HW at 20 DAS	37.2	28.2	27.9	30.1	38.5	42.3
T_2: PE atrazine at 0.5 kg ha^{-1} *fb* PW at 20 DAS	39.2	28.4	27.5	29.4	37.8	42.1
T_3: PE atrazine at 0.5 kg ha^{-1} + pendimethalin at 1 kg ha^{-1} (Tank mix)	38.0	24.0	22.2	27.8	36.4	40.9
T_4: PE atrazine at 0.5 kg ha^{-1} + pendimethalin at 1 kg ha^{-1} (Tank mix) *fb* HW at 20 DAS	38.3	23.7	22.1	27.9	37.0	41.0
T_5: EPOE topramezone at 25.2 g ha^{-1} at 20 DAS	37.6	38.3	39.3	23.4	19.9	30.5
T_6: PE atrazine at 0.5 kg ha^{-1} *fb* EPOE topramezone at 25.2 g ha^{-1} at 20 DAS	38.5	27.8	26.9	17.3	12.1	28.1
T_7: EPOE tembotrione at 122 g ha^{-1} at 20 DAS	37.3	38.4	39.8	25.9	21.7	32.2
T_8: PE atrazine at 0.5 kg ha^{-1} *fb* EPOE tembotrione at 122 g ha^{-1} at 20 DAS	38.3	27.9	27.1	18.5	12.7	29.5
T_9: Hand weeding twice at 20 and 45 DAS	39.5	40.1	40.5	41.4	41.7	41.8
T_{10}: Control	39.3	39.6	40.4	41.7	41.9	42.8
SEd	1.4	1.1	1.0	1.3	2.3	1.8
CD (P=0.05)	NS	2.6	2.3	3.2	5.7	4.2

Note: PE-Pre emergence; *fb*-followed by; HW-Hand weeding; PW-Power weeding; EPOE-Early post emergence

PE atrazine + pendimethalin (tank mix) *fb* HW at 20 DAS (T_4) recorded lower bacterial count which was comparable with PE atrazine + pendimethalin (tank mix) (T_3) at 3 and 15 DAS. Whereas, at 30, 60 and 90 DAS, lower bacterial count was recorded with EPOE tembotrione (T_7), EPOE topramezone (T_5), PE atrazine *fb* EPOE tembotrione (T_8) and PE atrazine *fb* EPOE topramezone (T_6) during pooled data of 2018 and 2019. The reason might be that the herbicides inhibited the microbial population immediately after application due to toxicity in soil environment. As the time passed on, with progressive degradation in herbicidal activity, the microbes adjusted themselves to the new environment and started building up. This was in accordance with the findings of Nalayini (2013) [13] and Sarkar *et al*. (2005) [14] who reported that pendimethalin (0.75 and 1.00) and fluchloralin (1.00 and 1.50) reduced the total soil bacterial population.

Soil actinomycetes

Weed management methods had significant influence on the actinomycetes population during 3, 15, 30, 60 and 90 DAS during *kharif 2018* and 2019 of pooled data (Table 2).

Table 2: Effect of different treatments on population of actinomycetes in soil (Pooled data of 2018-19 and 2019-20)

Treatments	0 DAS	3 DAS	15 DAS	30 DAS	60 DAS	90 DAS
T_1: PE atrazine at 0.5 kg ha^{-1} *fb* HW at 20 DAS	27.9	19.9	19.5	23.7	27.6	29.0
T_2: PE atrazine at 0.5 kg ha^{-1} *fb* PW at 20 DAS	28.3	20.2	19.8	23.5	27.5	29.0
T_3: PE atrazine at 0.5 kg ha^{-1} + pendimethalin at 1 kg ha^{-1} (Tank mix)	27.3	18.0	17.0	22.2	27.0	28.7
T_4: PE atrazine at 0.5 kg ha^{-1} + pendimethalin at 1 kg ha^{-1} (Tank mix) *fb* HW at 20 DAS	28.3	18.2	17.3	22.4	27.1	28.8
T_5: EPOE topramezone at 25.2 g ha^{-1} at 20 DAS	28.1	28.3	29.1	18.4	17.4	22.9
T_6: PE atrazine at 0.5 kg ha^{-1} *fb* EPOE topramezone at 25.2 g ha^{-1} at 20 DAS	27.9	19.7	19.3	15.1	11.9	21.0
T_7: EPOE tembotrione at 122 g ha^{-1} at 20 DAS	27.9	28.1	29.0	19.3	18.1	24.3
T_8: PE atrazine at 0.5 kg ha^{-1} *fb* EPOE tembotrione at 122 g ha^{-1} at 20 DAS	27.8	20.1	19.7	16.2	13.5	22.2
T_9: Hand weeding twice at 20 and 45 DAS	28.2	28.5	29.3	29.0	29.4	29.8
T_{10}: Control	28.3	28.4	29.2	29.0	29.6	29.8
SEd	0.7	0.4	0.6	0.5	1.1	1.4
CD (P=0.05)	NS	0.9	1.4	1.1	2.7	3.4

Application of PE atrazine + pendimethalin (tank mix) *fb* HW at 20 DAS (T_4) and PE atrazine + pendimethalin (tank mix) (T_3) at 3 and 15 DAS whereas at 30, 60 and 90 DAS, EPOE tembotrione (T_7), EPOE topramezone (T_5), PE atrazine *fb* EPOE tembotrione (T_8) and PE atrazine *fb* EPOE topramezone (T_6) recorded lower actinomycetes population which were on par with each other. Hand weeding twice at 20 and 45 DAS (T_9) and control (T_{10}) recorded higher population of actinomycetes at all stages of observation which were on par with EPOE topramezone (T_5) and EPOE tembotrione (T_7) at 3 and 15 DAS. PE atrazine *fb* HW at 20 DAS (T_1), PE atrazine *fb* power weeder at 20 DAS (T_2), PE atrazine + pendimethalin (tank mix) (T_3) and PE atrazine + pendimethalin (tank mix) *fb* HW at 20 DAS (T_4) were on par with T_9 and T_{10}.

Soil fungi

The effect of weed control methods on the population of fungi followed a similar trend as that of bacterial population and significant variations were observed (Table 3).

Table 3: Effect of different treatments on population of fungi in soil (Pooled data of 2018-19 and 2019-20)

Treatments	0 DAS	3 DAS	15 DAS	30 DAS	60 DAS	90 DAS
T_1: PE atrazine at 0.5 kg ha^{-1} *fb* HW at 20 DAS	20.1	19.3	19.1	20.6	25.1	27.1
T_2: PE atrazine at 0.5 kg ha^{-1} *fb* PW at 20 DAS	20.5	19.5	19.3	20.3	24.8	27.0
T_3: PE atrazine at 0.5 kg ha^{-1} + pendimethalin at 1 kg ha^{-1} (Tank mix)	19.6	16.7	16.4	19.0	24.3	26.3
T_4: PE atrazine at 0.5 kg ha^{-1} + pendimethalin at 1 kg ha^{-1} (Tank mix) *fb* HW at 20 DAS	20.1	17.2	16.6	19.2	24.5	26.4
T_5: EPOE topramezone at 25.2 g ha^{-1} at 20 DAS	20.3	21.0	21.8	16.3	14.7	21.8
T_6: PE atrazine at 0.5 kg ha^{-1} *fb* EPOE topramezone at 25.2 g ha^{-1} at 20 DAS	20.0	19.2	19.0	12.6	10.9	20.0
T_7: EPOE tembotrione at 122 g ha^{-1} at 20 DAS	19.9	21.0	21.7	17.1	15.7	21.9
T_8: PE atrazine at 0.5 kg ha^{-1} *fb* EPOE tembotrione at 122 g ha^{-1} at 20 DAS	20.0	19.3	19.2	13.8	12.1	20.7
T_9: Hand weeding twice at 20 and 45 DAS	20.4	21.4	22.3	24.0	25.6	27.9
T_{10}: Control	20.6	21.3	22.2	24.2	25.7	28.3
SEd	0.6	0.5	0.4	0.8	0.8	1.0
CD (P=0.05)	NS	1.2	0.8	1.7	1.9	2.4

Control (T_{10}) and hand weeding twice at 20 and 45 DAS (T_9) recorded higher population of fungi at all stages of observation. PE atrazine + pendimethalin (tank mix) *fb* HW at 20 DAS (T_4) and PE atrazine + pendimethalin (tank mix) (T_3) restricted the growth of fungi and recorded lower population from 3 DAS up to 15 DAS. At 30, 60 and 90 DAS, EPOE tembotrione (T_7), EPOE topramezone (T_5), PE atrazine *fb* EPOE tembotrione (T_8) and PE atrazine *fb* EPOE topramezone (T_6) registered lower population of fungi which were comparable with each other. The microbial population started to recover slowly after 30 days after herbicide application irrespective of the treatments during pooled data of *kharif 2018* and 2019.

Conclusion

Microbial population was significantly lesser in pre emergence atrazine at *fb* either early post emergence topramezone at 20 DAS or early post emergence tembotrione at 20 DAS from initial stage to 60 DAS, later it started increasing but it was lesser than control. Unweeded control did not affect the soil microflora from initial to till harvest of the maize crop. Similar results are in line with Tu and Bollen (1968) [15] who had mentioned herbicides have varying effect on soil microbial populations depending on herbicide concentrations and the microbial species present. Low residue levels can enhance population while higher levels can cause population declines.

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