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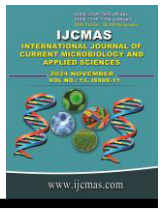

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Impact of Herbicides on Physiological Growth and Yield and Enhancement of Weed Control Efficiency in Hybrid Maize

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A B S T R A C T

Weeds are the most important biotic constraints to maize production. Yield losses in maize due to weeds depend on several factors such as weed emergence time, weed density and type of weeds. If the weeds left uncontrolled, it results in 100% yield loss. Since, labour availability to manual weeding and higher wages, it is necessary to have the strategy of chemical control of weeds in appropriate time to attain target yield and economic benefit. In this view, field experiments were conducted at Maize Research Station, Vagarai, Tamil Nadu (India) during the season *kharif* of the years 2015, 2016 and 2017 under irrigated ecosystem in maize hybrid (TNMH-Co 6) to develop weed management options with new herbicide molecules. The experiments were laid out in RBD and replicated thrice. The weed management options *viz*., pre and post emergence herbicide applications in different doses and time with conventional hand weeding. The trials were also compared with Weedy check (control) and Weed free check. The result of the experiment revealed that the weed control efficiency was higher under pre-emergence application of pendimethalin@1000mla.i./ha *fb* atrazine @ 750 g a.i./ha + 2, 4 D amine salt. Higher grain yield (9768 kg/ha) was registered under atrazine (1500 g a.i./ha) pre-emergence *fb* halosulfuron (60 g/ha) at 25 DAS as PoE at 50 DAS, which was on par with weed free check, application of pendimethalin @ 1000 ml a.i./ha as PE *fb* atrazine @ 750 g a.i./ha + 2, 4 Damine (75%) at 25 DAS as PoE, application of atrazine @ 250 g a.i./ha + One hand weeding at 30-35 DAS and application of tembotrione @ 120ga.i./ha as PoE at 25 DAS.

Introduction

Maize (*Zea mays* L.) is the second most important cereal crop in the world in terms of total food production. It is grown for fodder as well as for grain. The grains of maize are used in a variety of ways by the human beings. Recently, with the release of improved cultivars and hybrids, the grain yield has been increased but still the maize crop faces many problems. Weeds are one of the most important factors affecting maize production. They cause yield losses worldwide with an average of 12.8% despite weed control and 29.2% in the case of no weed control (Oerke and Steiner, 1996). Maize, being a rainy season and widely spaced crop, gets infested with variety

of weeds and subjected to heavy weed competition, which often inflicts huge losses ranging from 28 to 100 per cent (Patel *et al.,* 2006). It is confirmed from the study of Akbar *et al.,* (2019) that weeds are the major challenge in Conservation Agriculture (CA) crop production systems, where almost 16 to 42% yield reduction is occurred due to weed infestation and one-third of the total cost of cultivation is spent on weeding.

CA based maize production under no till systems with different chemical weed control is a potential means for controlling weeds and more economic when compared to hand weeding. Pre-emergence application of atrazine@0.5kga.i./ha+handweeding and interculturing at 30 DAS orpendimethalin@0.9kga.i./ha as pre-emergence+hand weeding and inter culturing at 30 DAS would be the better option under south Saurashtra Agro-climatic conditions (Mathukia *et al.,* 2014). They have also reported that sequential application of atrazine 0.75 kga.i./ha *fb* 2,4-D @ 1.0 kg/ha is on par with weed free treatment. Annual grass weeds may be controlled by mechanical weeding or by the split application of graminicides. Post-emergence graminicides have also been registered on maize and is usually used in a spray program with pre-emergence herbicides at or just after planting followed by post-emergence herbicides when grasses are at 4 to 6 leave stage (Maize Information Guide, 2014). Higher grain yield in these treatments could be attributed to improved yield components such as higher number of grains/cob, higher grain weight/cob and 100 grain weight.

The improvement in yield components was due to improved growth attributes such as higher total dry matter production and leaf area index. Thus, the improvement in growth and yield components was as a consequence of lower crop-weed competition, which shifted the balance in favour of crop in the utilization of nutrients, moisture, light and space (Shantveerayya and Agasimani, 2012).

Grain yield is a function of the cumulative behavior among various yield determining components *viz.,* the number of cobs per plants, cob length, number of grains per cob and 1000 grain weight which showed variations by prevailing growing conditions and various crop management practices. Significantly higher grain yield (78.28 % grains increased over check) (8,071 kg/ha) with manual hoeing which was statistically at par with Pendimethalin@1050ga.i./ha (75.37%) and Pendimethalin + Prometryn @ 1225 g a.i./ha (69.86 %) was recorded by Tahir *et al.,* (2009). Therefore, weed control is an important management practice for maize production that should be carried out to ensure optimum grain yield.

Megersa *et al.,* (2018) also reported that preemergence herbicide of weed knock at 2 lit/ha+HW at 40 DAS on maize provided the highest grain yield (58.13 q/ha) with 33 % yield advantage over weedy check. With these ideas, the present study was taken upto find out the suitable weed management practice in maize under irrigated condition.

Materials and Methods

Field experiments were conducted at Maize Research Station, Vagarai during *kharif* 2015-2017 to develop weed management options with new herbicide molecules in irrigated maize. The experiment was laid out in RBD replicated thrice with the following 12 treatments.

T_1 - Control (Weedy check), T_2 - Weed free, T_3 - Atrazine @ 1500 g a.i./ha PE, T_4 - Atrazine (750 ga.i./ha)+Pendimethalin(750mla.i./ha)PE, T_5-Atrazine (750 g a.i./ha) + 2,4-D Amine (75%) at 25 DAS as PoE, T_6 - Halosulfuron 60 g a.i./ha at 25 DAS, T_7 - Atrazine @ 1500 g a.i./ha PE *fb* Halosulfuron 60 ga.i./ha 25 DAS, T_8-Tembotrione120ga.i./ha PoE at 25 DAS, T_9 - Pendimethalin (1000 ml a.i./ha) PE *fb*Atrazine (750 g a.i./ha) + 2,4-D Amine (75%) at 25 DAS, T_{10}-Atrazine@1500kga.i./haPE*fb*Tembotrione120ga.i./ha)PoE at 25 DAS, T_{11}-Atrazine @ 250 g a.i./ha + One hand weeding at 30-35 DAS and T_{12} - Atrazine@250 g a.i./ha + 2,4 D @1000 g/ha at 20-25 DAS. The research station is located at a latitude of 10º57' N, longitude of 77 º56' E and altitude of 254 m MSL.

The average rainfall in this area is around 600 mm. The soil type of experimental plot was red sandy loam. The soil pH was 7.1, EC - 0.28 dS/m, Organic carbon - 0.32 %, available soil N - 110 kg/ha, available P_2O_5-13.6 kg/ha and the available K_2O-368kg/ha. The average maximum temperature prevailed during the cropping period was 34.8º C and the average minimum temperature was 21.1ºC. Observations on weed parameter, growth, yield parameters and yield were taken and analysed. The pooled data of the year 2015, 2016 and 2017 were statistically analyzed and the result of the effect of weed management practices on weed dry matter, weed control efficiency grain yield and stover yield were calculated and presented.

Results and Discussion

Weed dry matter

The dry weights of weeds were significantly reduced with the application of herbicides compared to weedy check. The dry matter of broad leaved weeds was higher under control (T_1) (204.6 g/m^2 and178.4no/m^2 at 50 DAS and at harvest, respectively). On 50 DAS, next to weedy check treatment (T_1), the treatment T_6 (halosulfuran @ 60 ga.i./ha at 25 DAS), T_8(tembotrione@120ga.i./ha at 25 DAS) and T_4(atrazine@750ga.i./ha+pendimethalin @ 750 ml a.i./ha as PE) had higher weed dry weight, respectively and were on par with each other. Apart from the weed free treatment (T_2), lesser weed dry weight (61.1g/m^2) was recorded in T_{11} (atrazine 0.25 kg a.i./ha + one hand weeding at 30-35 DAS). At the time of harvest, the dry weight of broad leaved weeds was significantly higher (178.4 g/m^2) in T_1 (weedy check) and it was on par with T_3 (atrazine @1500 g a.i./ha PE) and T_6 (halosulfuran @ 60 g a.i./ha at 25 DAS) (147.7 and 145.4 g/m^2 respectively). Apart from weed free treatment (T_2), significantly lesser weed dry weight was recorded in T_5 (atrazine (750 g a.i./ha) +2,4-DAmine(75%) at 25 DAS as PoE) and T_{10}(Atrazine @ 1500 g a.i./ha PE *fb* tembotrione 120 ga.i./ha)PoE at 25 DAS) (45.6 and 45.7 g/m^2, respectively). It was evidenced by Akbar *et al.,* (2019) that the application of Atrazine as pre-emergence followed by (fb)tembotrione+atrazine as post-emergence found best combination and this combination reduced the weed dry matter to the tune of 98.7 and 97.9 % at 40 and 60 DAS, respectively which ultimately resulted in significantly higher grain yields (11.57 t/ha) with maximum net returns.

The grass weed dry weight was significantly higher (20.3g/m^2) in T_1 (weedy check) and was on par with T_5(atrazine (750 g a.i./ha) + 2,4-D Amine (75%) at 25 DAS as PoE) at 50 DAS, whereas, lesser grass weed dry weight (0.7g/m^2) was recorded in T_{11} (Atrazine@250ga.i./ha+onehandweeding at 30-35 DAS) followed by T_8 (Tembotrione(120 ml a.i./ha) at 25 DAS as PoE).

There was also a significant difference in weed dry weight of grass weeds at harvest stage. Weedy check (T_1) had significantly higher grass weed dry weight (45.6g/m^2), which was on par with T_{12}(Atrazine @ 0.25 kg a.i./ha + 2,4 D @ 1000 g a.i./ha at 20-25 DAS). Significantly lesser weed dry weight was registered in T_4 and followed by T_3 (7.9 and 9.2 g/m^2 respectively).

Ravisankar *et al.,* (2013) reported that atrazine effectively controlled majority of broad leaved and grassy weeds at earlier stages of maize growth. Application of atrazine at 0.5 kg/ha as pre-emergence followed by intercultivation at 35 DAS in maize significantly reduced the total weed density and weed dry weight. The result is coincides with the findings of Megersa *et al.,* (2018) that the maximum dry weight was counted from weedy plots. Herbazed at 2 lit/ha+HW @ 40 DAS provided the minimum total fresh and dry weight of weeds after 80 DAS which was statistically the same with other treatments; whereas the maximum total fresh and dry weight of was from weedy plots, respectively.

Weed Control Efficiency

Higher weed control efficiency (100%) was calculated in T_2(Weed free treatment). Apart from T_2 treatment, higher weed control efficiency (65.1%) was associated with T_{11}(atrazine @ 250 g a.i./ha + one hand weeding at 30-35 DAS) followed by T_9 (60.2 %)(pendimethalin (1000mla.i./ha) as pre-emergence *fb* atrazine(750ga.i./ha)+ 2,4 D amine (75%) at 50 DAS and T_{10} (atrazine (1500g a.i./ha) pre-emergence *fb* tembotrione (120 ml a.i./ha)(59.8%). At the time of harvest the weed control efficiency was higher in T_9 (pendimethalin (1000 mla.i./ha) as pre-emergence *fb* atrazine (750 g a.i. /ha) +2,4 D amine (75%) followed by T_{10} (atrazine @ 1500 ga.i./ha PE *fb* tembotrione 120 ga.i./ha)PoE at 25 DAS) (except T_2-weedfree). Next to weedy check (T_1), application of halosulfuron @ 60 g a.i./ha (T_6) had the lesser weed control efficiency (3.4 % and 6.6 % on 50 DAS and at harvest respectively).

The weed control efficiency was higher in absolute weed free plots as well as where one hand weeding done after the application of atrazine @ 250 g a.i./ha(T_{11}) as pre emergence herbicide. Either the higher dose of herbicide (atrazine@ 1500g a.i./ha as PE) or the post emergence herbicide (tembotrione 120 g a.i./ha or atrazine @ 750 g a..i./ha + 2,4 D amine at 25 DAS application might be the reason to higher weed control efficiency in maize. The research evidences of Shankar *et al.,* (2015) have shown that higher weed control efficiency at harvest was found with application of atrazine (50%) @1.25kg/ha+ pendimethalin (50%) @2.5 lit/ha which was on par with rest of the chemical treatments except atrazine 50 EC@ 2.5lit/ha, Metasulfuron Methyl 20EC@0.02 kg/ha, Pendimethalin 30 EC @ 5 lit/ha, one hand weeding and hand weeding twice, respectively and this lend support to

the present result. Kamble *et al.,* (2015) reported that higher weed control efficiency at harvest was found with application of atrazine(50%)@1.25kg+pendimethalin (50%) @ 2.5 lit/ha (7.33) and which was on par rest of the chemical treatments except atrazine 50 EC -2.5 lit/ha – Metasulfuron Methyl 20 EC-0.02kg/ha, pendimethalin 30 EC-5lit/ha- one hand weeding and hand weeding in twice respectively. Kolage *et al.,* (2004) found that the maximum weed control efficiency was observed in weed free check followed by application of atrazine @1 kg/ha and PE application of Atrazine 0.5kg/ha*fb* one hand weeding. This result was supported as the highest weed control efficacy was observed in Herbazed + One times hand weeded at 40 DAS, followed by two times hand weeded plots (97.1%). This shown that supplementation of pre-panting herbicides with one-time hand weeding at 40DAS improved WCE% than two times hand weeding at25 and 40 DAS alone; which was due to decrement in weed density and fresh weight that resulted from vigor growth of crop and high competition for resources over weeds (Megersa *et al.,* 2018).

Yield and economics

Among the different weed management practices higher grain yield (9768 kg/ha) was registered in T_7 (atrazine (1500 g a.i./ha as pre-emergence) *fb* halosulfuron (60 g a.i./ha) at 25 DAS as PoE) at 50 DAS), which was on par with T_2 (weed free) (9052 kg/ha). This was mainly due to the lesser cropweed competition during the early and critical stages ofthe maize crop. Santveeraiyya and Agasimani (2012) reported that higher grain yield of maize of (7.72 t/ha) was obtained under weed free check. It was mainly due to minimum crop-weed competition throughout the crop growth period, thus enabling the crop for maximum utilization of nutrients, moisture, light and space which had influence the growth and yield components.

The same was on par with T_9-Pendimethalin (1000 ml a.i./ha) PE *fb* atrazine (750 ga.i./ha) + 2,4-D amine (75%) at 25 DAS), T_{11} - Atrazine@ 250 g a.i./ha + one hand weeding at 30-35 DAS and T_8-Tembotrione 120 ga.i./ha PoE at 25 DAS (8479 kg/ha, 8775 kg/ha and 8549 kg/ha, respectively). The reports of Tahir *et al.,* (2009) who found that manual hoeing and pendimethalin pre-emergence application can be more effective in controlling weeds as compared to all other treatments without compromising maize grain yield due to weeds lend support to the present result. Kamble *et al.,* (2015) has also reported that pre-emergent application of atrazine@1kg*a.i.*/ha recorded significantly higher grain yield (7079 kg/ha) over rest of the weed control treatments and was on par with weed free check. The higher yield with these practices was due to improvement in yield attributing characters like 100 seed weight and seed weight per cob. The result was also supported with the findings of Saini and Angiras (1998) that higher yield was obtained by the application of atrazine@1.5kg/ha as pre-emergence followed by atrazine@0.75 kg/ha.

The net returns and benefit cost ratio were higher (Rs.88,426/ha and 2.46) in T_7 (atrazine 1.5 kg a.i./ha as pre-emergence *fb* halosulfuron 60g/ha at 25 DAS as PoE at 50 DAS) followed by T_9 (pendimethalin (1000 mla.i./ha) PE *fb* atrazine (750 g a.i./ha) + 2,4-D Amine(75%) at 25 DAS)(Rs.77,176/ha and 2.46) due to significant higher yield and reduction in cost of cultivation by the application of post emergence application of halosulfuron(T_7) and post emergence application of atrazine + 2, 4 D amine salt at 25 DAS (T_9). Shantveerayya and Agasimani (2012) reported that the benefit cost ratio (BCR) was higher (3.47) in sequential application of atrazine 0.75 kg/ha *fb*2,4-D1.00kg/ha *fb* mechanical weeding (3.18), 2 hand weeding (25 and 45 DAS+1intercultural operation at 30 DAS). This was mainly due to higher economic yield, net returns and lower cost of cultivation.

Maize is an important cereal crop of India grown in both *kharif* and *rabi* season. This crop has a very high yield potential, particularly the hybrids which may produce as high as 6 t/ha during *kharif* and more than 10t/ha during *rabi* season but the average yield (2.5t/ha) is considered to be very low due to various constraints. Wide row spacing in maize coupled with favourable environment allows luxuriant weed growth which may reduce the yield by 30-90%. In addition, maize is generally raised under marginal conditions with meager inputs which make it poor competitor. Timely weed control in maize has become the essential for realizing its potential yield. Weed control through use of herbicides (chemical) assumed a greater significance/importance due to their accessibility, selective and quick action after the discovery of 2, 4- D in 1935 for broad leaved weeds. But over reliance on herbicide use sometimes may cause residual toxicity to succeeding crops and ground water contamination. Massive pollution pressures on the environment from different sources including herbicide use necessitate sustained efforts of exploring non-chemical weed control.

Table.1 Effect of new herbicide molecules on weed dry weight (g/m2) and weed control efficiency in irrigated maize

Treatment	Weed dry weight at 50 DAS(g/m^2)			Weed dry weight at harvest(g/m^2)			Weed control efficiency (%)	
	Broad leaved weeds	Grass weeds	Sedges	Broad leaved weeds	Grass weeds	Sedges	50DAS	**Harvest**
T1-Control (Weedy check)	14.21 (205)	4.50 (20)	0.0 (0)	13.23 (178)	6.68 (46))	0.0 (0)	0	**0**
T2-Weed free	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	100	**100**
T3-Atrazine@ 1500ga.i./ha PE	11.0 (122)	3.52 (13)	0.43 (0.6)	12.12 (148)	3.0 (9)	0.43 (0.6)	41.7	**40.2**
T4-Atrazine(750ga.i./ha)+Pendimethalin (750 mla.i./ha)PE	9.32 (88)	1.94 (4)	1.09 (2)	9.51 (91)	2.64 (8)	0.0 (0)	56.5	**53.5**
T5-Atrazine(750ga.i./ha)+2,4-DAmine(75%)at25DASas PoE	9.41 (93)	4.31 (19)	0.0 (0)	6.45 (46)	5.00 (26)	0.0 (0)	58.4	**63.9**
T6-Halosulfuron 60 ga.i./haat25 DAS	12.04 (146)	3.64 (14)	0.0 (0)	12.06 (146)	4.55 (21)	0.0 (0)	3.4	**6.6**
T7-Atrazine@1500ga.i./ha PE*fb* Halosulfuron 60 ga.i./ha25 DAS	9.13 (84)	3.72 (14)	0.0 (0)	7.43 (58)	4.29 (18)	0.0 (0)	55.0	**59.8**
T8-Tembotrione120ga.i./haPoE at25DAS	11.45 (134)	1.83 (4)	0.0 (0)	10.27 (108)	5.40 (30)	0.0 (0)	34.0	**32.5**
T9-Pendimethalin (1000 mla.i./ha)PE*fb*Atrazine(750 ga.i./ha)+2,4-DAmine(75%)at25DAS	9.51 (91)	2.64 (7)	0.19 (0.1)	8.34 (70)	3.57 (14)	0.0 (0)	60.2	**77.2**
T10-Atrazine@ 1500ga.i./ha PE*fb* Tembotrione120 ga.i./ha)PoE at25DAS	9.83 (97)	3.41 (12)	0.0 (0)	6.33 (46)	3.65 (14)	0.0 (0)	59.8	**74.7**
T11–Atrazine@250ga.i./ha+ Onehandweedingat30–35DAS	7.77 (61)	0.47 (0.7)	0.0 (0)	7.66 (59)	5.21 (29)	1.02 (3)	65.1	**42.1**
T12–Atrazine@250ga.i./ha+2,4D@1000g/haat20–25DAS.	10.83 (113)	2.55 (7)	0.0 (0)	8.72 (79)	6.65 (45)	0.0 (0)	23.2	**20.1**
SEd	1.20	0.65	0.35	1.43	0.82	0.46	-	**-**
CD (P=0.05)	**2.50**	**1.35**	**NS**	**2.96**	**1.70**	**NS**	**-**	**-**

(Figures in parenthesis are original values)

Table.2 Effect of new herbicide molecules on yield and economics irrigated maize.

Treatment	Grain yield (kg/ha)	Stover yield (kg/ha)	Net returns (Rs./ha)	Benefit Cost ratio
T1-Control (Weedy check)	6846	8860	44768	**1.73**
T2-Weed free	9052	9065	66937	**2.00**
T3-Atrazine@1.5kga.i./haPE	7545	8476	59459	**2.10**
T4-Atrazine(750 ga.i./ha)+Pendimethalin(750mla.i./ha)PE	8254	9087	70087	**2.29**
T5-Atrazine(750 ga.i./ha)+2,4-DAmine(75%)at25DASas PoE	7402	9078	57810	**2.05**
T6-Halosulfuron60ga.i./haat25DAS	7826	9457	61162	**2.07**
T7-Atrazine@1.5kga.i./haPE*fb*Halosulfuron60ga.i./ha25DAS	9768	7980	88426	**2.56**
T8-Tembotrione120ga.i./haPoEat25DAS	8479	9069	73358	**2.36**
T9 - Pendimethalin (1000 ml a.i./ha) PE *fb* Atrazine (750 g a.i./ha) + 2,4-DAmine (75%)at25DAS	8725	9603	77176	**2.46**
T10 - Atrazine @ 1.5 kg a.i./ha PE *fb* Tembotrione 120 g a.i./ha) PoE at 25DAS	8229	8859	67065	**2.16**
T11–Atrazine@0.25kga.i./ha+1Handweedingat30–35DAS	8549	9198	63494	**1.98**
T12–Atrazine@0.25kga.i./ha+2,4D@1kg/haat20–25DAS.	7661	8580	59258	**2.03**
SEd	658	622	-	-
CD(P=0.05)	**1365**	**NS**	-	-

Figure.1 Effect of new herbicide molecules on weed control efficiency in irrigated maize.

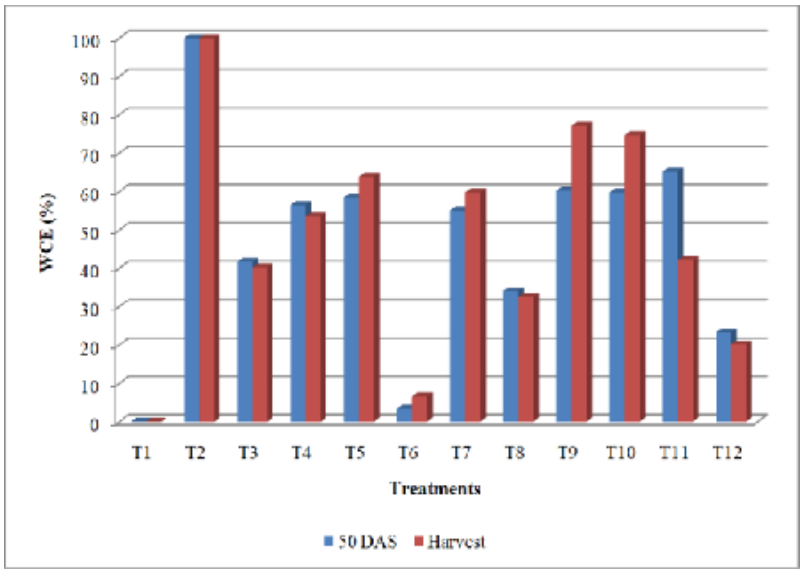
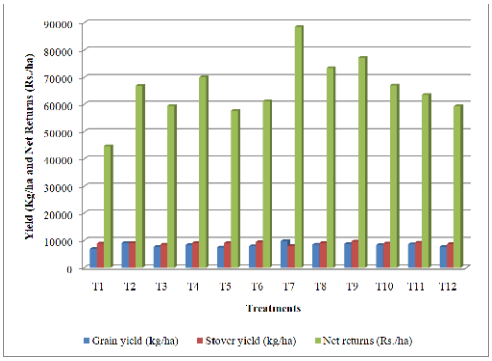


Figure.2 Effect of new herbicide molecules on yield and economics irrigated maize.



In order to minimize their ill effects, several crop husbandry techniques like stale seed bed technique (a practice of allowing to germinate the weed seeds and killing them subsequently before sowing crop), tillage practices (conservational/conventional), soil solarization (mulching) planting techniques (raised furrows) could be combined in an integrated way to make weed control strategy effective and economical.

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Author Contributions

P. Thukkaiyannan: Investigation, formal analysis, writing—original draft. N. Satheeshkumar: Validation, methodology, writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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