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Weed persistence, crop resistance and phytotonic effects of herbicides in hybrid maize (*Zea mays* L.)

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Abstract
Results of experiment conducted during Kharif season of 2016 at Research Station, OUAT, Bhubaneswar with eight different treatments of herbicides and combinations on yield of hybrid maize revealed that Weed persistence index at all the stages of crop growth that the hand weeding treatment gave the higher persistence index, indicating resistance of escaped weeds to control measures. Crop resistance index were maximum in hand weeding treatments at 20 and 40 DAS followed by atrazine @ 1.0 kg ha at 1 DAS as pre-emergence and tembotrione @ 120 g/ha at 25 DAS (POE) consistently increased the crop resistance at all the crop developmental stages of the crop. Atrazine @ 750 g/ha+ pendimethalin @ 750 g/ha as pre-emergence at 1 DAS recorded higher values of weed management index of 0.63 and 0.65 at 50 and 75 DAS, respectively compared with other weed management treatments. The same treatment also enhanced the agronomic weed management index and integrated weed management index.

Keywords: Weed persistence, crop resistance, phytotonic effects, herbicides, hybrid maize, *Zea mays* L.

Introduction
Maize (*Zea mays* L.) is one of the most crucial and strategic crop in the world. Maize plays a vital role in ensuring food security as well as nutritional security through quality protein. The crop has immense potentiality with special characteristics that include its carbon pathway (C_4), wider adaptability, higher multiplication ratio, high yielding ability and high versatile use, therefore called as "Queen of Cereals". The United States of America (USA) is the largest producer of maize and contributes nearly 35% of the total production in the world. In India, maize is the third most important food crop after rice and wheat. In India, it is cultivated over an area of 8.69 m ha with production of 21.80 m tonnes and productivity is 2509 kg ha^{-1} in 2015-16 (AICRP on maize 2016) [7]. The area under maize is increasing in the state because high profitable option has been realised by the farmers. Initial slow growth of maize is more sensitive to weed competition during its early growth period. Wider row spacing of the crop provide enough opportunity for the weeds to emerge and offer severe competition. The growth of maize plants in the first three to four weeks is rather slow and during this period weeds establish rapidly and take competitive advantage (Srividya *et al.*, 2011) [2]. Kumar *et al.* (2015) [5] stated that in the rainy season, the emergence of maize and weeds was simultaneous and the first 20 to 60 days was the most critical period of competition for the crop. Use of pre and post emergence herbicides at temporal variation may help in avoiding the problem of weeds throughout the growth stages. The choice of weed control methods largely depend on effectiveness and economics.

Herbicides are used to control weeds in crop as pre or post emergence application which reduce the population of weeds significantly resulting in higher yield and profit. Some times, the pesticides apart from harming target species also affect the non target living being like microflora or fauna or biochemical reaction in soil and plant which may some times augment yield (Phytotonic effect) or some times produce detrimental effect (phytotoxic) on plant. Scientists many a times ignore such action of herbicides as it requires several cumbersome studies for the purpose. Now, in the days of Global warming and climate change, it is needful to conserve ecosystem and biodiversity along with sustained production of higher yield. Mishra and Mishra (1997) [1] have tried to quantify weed persistence, crop resistance and phytotonic effect of herbicidal treatments by using mathematical formula basing on growth characters where the effect of herbicide treatment can be easily identified which can give an indication basing on which further studies can be under taken for conformation.

Materials and Methods

The experimental was conducted in the Agronomic Main Research Farm of Orissa University of Agriculture and Technology, Bhubaneswar. The soil of the experimental field was sandy loam in texture, acidic in reaction (pH 4.68) and available nitrogen (233.0 kg/ha), phosphorus (23.2 kg/ha) and potassium (153.1kg/ha). The experiment was laid out in randomized block design with ten treatments and three replications. The herbicides in combination and sequential application comprised of atrazine @ 1.0 kg/ha as pre-emergence (PE) at 1 days after sowing (DAS), atrazine @ 750 g/ha+ pendimethalin @ 750 g/ha as PE at 1 DAS, atrazine @ 750 g/ha + 2,4-D amine salt @ 400 g/ha as post emergence (PoE) at 25 DAS, halosulfuron @ 60 g/ha as PoE at 25 DAS, tembotrione @ 120 g/ha as PoE at 25 DAS, atrazine @ 1.0 kg/ha as PE at 1 DAS followed by halosulfuron @ 60 g/ha at 25 DAS, pendimethalin @ 1.0 kg/ha as PE at 1 DAS followed by atrazine @ 750 g/ha + 2,4-D amine salt @ 400 g/ha as PoE at 25 DAS and atrazine @1.0 kg/ha as PE at 1 DAS followed by tembotrione @ 120 g/ha at 25 DAS were tested with hand weeding at 20 and 40 (DAS) and un-weeded control. Total rainfall of 841 mm was received during cropping period July, August, September and October 2016. The rainfall received during July and October were 222.2 and 132.8 mm, respectively. Mean normal relative humidity for morning and afternoon were 91.9% and 80.3% respectively.

Floristic composition of weeds

The occurrence of broad leaved weeds was higher than the grasses and sedge. Basing upon the frequency of infestation, the dominant broad leaved was *Ludwigia parviflora*, *Commelina benghalensis* and *Celosia argentea*. Among the grasses *Digitaria sanguinalis*, *Eleusine indica*, *Cynodon dactylon* and *Echinochloa colonum* were found more frequent and sedge weed *Cyperus rotundus* was found less frequent occurring to throughout the crop growth stages

Crop resistance index (CRI): (dry matter production by crop in the treatment plot/dry matter production by crop in the control plot) x (dry matter production of weed in control plot/dry matter production of weeds in treatment plot).

Weed persistence index (WPI): (Dry weight of weeds in treated plot/dry weight of weeds in control plot) x (weed count in the control plot / weed count in the treated plot).

Weed index: Weed index was calculated by using the following formula and expressed in percentage. (Mishra and Mishra 1997) [1]

$$\text{Weed Index (WI) \%} = \frac{X - Y}{X} \times 100$$

Where, X = Total yield from the weed free plot
Y = Total yield from the treatment for weed index has been calculated

Weed management index (WMI): Weed management index was calculated as suggested by Mishra and Mishra (1997) [1]

$$\frac{\text{Percent yield over control}}{\text{Percent control of weeds}}$$

Agronomic management index (AMI)

$$\frac{\text{Percent yield over control} - \text{percent control of weeds}}{\text{Percent control of weeds}}$$

The AMI was calculated as per formula given by Mishra and Mishra (1997) [1]

Integrated weed management index (IWMI)

$$\frac{(\text{WMI} + \text{AMI})}{2}$$

The IWMI was found out as suggested by Mishra and Mishra (1997) [1]

Weed persistence index (WPI)

Weed persistence index is presented at all the stages of crop in Table 16 showed that the hand weeding treatment gave the higher persistence index throughout the crop growth stages indicating resistance of escaped weeds to control measures. The lower persistence of escaped weeds recorded by atrazine @ 1.0 kg/ha at 1 DAS (PE) with sequence of halosulfuron @ 60 g/ha at 25 DAS (POE) followed by atrazine @ 1.0 kg ha at 1 DAS as pre-emergence with sequence of tembotrione @ 120 g/ha at 25 DAS (POE) and atrazine @ 750 g/ha + pendimethalin @750 g/ha at 1 DAS as pre-emergence at 50, 75 and harvest stages indicated the broad spectrum effect in controlling the weeds.

Crop resistance index (CRI)

The crop resistance index (Table 23) indicating increased vigor of crop plant due to weed management measures pointed out that the hand weeding at 20 and 40 DAS and atrazine @ 1.0 kg ha at 1 DAS as pre-emergence followed by tembotrione @ 120 g/ha at 25 DAS (POE) consistently increased the crop resistance at all the crop developmental stages of the crop. It indicated much less harmful effect of herbicides on crop as compared to other treatments. Un-weeded control recorded the lowest value of CRI (1.0) indicating highest harmful effect on crop.

Weed management index, agronomic weed management index and integrated weed management index

The data on weed management index, agronomic weed management index and integrated weed management index depicted in Table 25 indicated that atrazine @ 750 g/ha+ pendimethalin @ 750 g/ha as pre-emergence at 1 DAS recorded higher values of weed management index of 0.63 and 0.65 at 50 and 75 DAS, respectively compared with other weed management treatments. The same treatment also enhanced the agronomic weed management index and integrated weed management index. The next best result in increasing the integrated weed management index was observed in atrazine @1.0 kg/ha (PE) at 1 DAS followed by tembotrione @ 120 g/ha at 25 DAS.

Grain yield

Weed management treatments exerted the significant effect in increasing the grain yield over un-weeded control (Table 24). Pre-emergence application of atrazine @750 g/ha+ pendimethalin @ 750 g/ha at 1 DAS recorded the highest grain yield (7.00t/ha). It was at par with atrazine @1.0 kg/ha(PE) at 1 DAS followed by tembotrione @120 g/ha(POE) at 25 DAS (6.74 t/ha) and atrazine @ 750 g/ha + 2,4-D amine salt @ 400 g/ha at 25 DAS as post emergence (6.57t/ha), hand weeding at 20 and 40 days after sowing (6.47 t/ha), pendimethalin@1.0 kg/ha (PE) at 1 DASfollowed by atrazine @ 750 g/ha + 2,4-D amine salt @ 400 g/ha (PoE)at 25 DAS (6.26 t/ha) and atrazine @1.0 kg/ha (PE) at 1 DAS

followed by halosulfuron @ 60 g/ha (POE) at 25 DAS (6.10 t/ha). The grain yield obtained among the herbicidal treatments was the lowest in halosulfuron@ 60 g/ha as P0E. Weedy check treatment recorded the lowest grain yield of 4.49t/ha.

Stover yield

Data pertaining to stover yield indicated that significant variation was observed due to weed control treatment (Table 26). The stover yield of maize was increased significantly with the atrazine @750 g/ha+ pendimethalin @ 750 g/ha as pre-emergence at 1 DAS (7.57 t/ha) which was found at par with all other treatment except tembotrione @ 120 g/ha as post emergence application and weedy check treatment. Absence of weed control in weedy check recorded the lowest stover yield (5.79t/ha).

Weed Index

Data pertaining to weed index computed on the basis of maximum grain yield as presented in Table 24 showed that un weededcontrol recorded themaximum yield loss of 35.89%. Minimum yield loss was observed in atrazine @1.0 kg /ha(PE) at 1 DAS followed by tembotrione @120 g/ha(POE) at 25 DAS (3.72%) and atrazine @750 g/ha + 2,4-D Amine salt @ 400 g/ha at 25 DAS as post emergence (6.14%) as compared with hand weeding at 20 and 40 days after sowing (7.57%).

Table 1: Effect of weed control treatments on weed persistence index at different crop stages.

Treatment	25 DAS	50 DAS	75 DAS	Harvest
Weedy check	1.00	1.00	1.00	1.00
Hand weeding at 20 and 40 days after sowing (DAS)	2.03	1.09	1.16	1.22
Atrazine @ 1.0 kg/ha as pre-emergence (PE) at 1 DAS	0.47	0.39	0.39	0.50
Atrazine @750 g/ha + pendimethalin @750 g/ha (PE) at 1 DAS	0.88	0.31	0.40	0.70
Atrazine @750 g/ha + 2,4-D Amine salt @ 400 g/ha as post emergence (PoE) at 25 DAS	0.95	0.64	1.07	0.91
Halosulfuron @ 60 g/ha (PoE) at 25 DAS	1.14	0.64	0.61	0.45
Atrazine @1.0 kg/ha at 1 DAS (PE) followed by halosulfuron @60 g/ha (PoE) at 25 DAS	0.39	0.26	0.30	0.36
Tembotrione @120 g/ha (PoE) at 25 DAS	1.09	0.66	0.66	0.73
Pendimethalin @1.0 kg/ha at 1 DAS (PE) followed by atrazine @ 750 g/ha + 2,4-D amine salt @ 400 g/ha (PoE) at 25 DAS	0.83	0.99	0.98	1.22
Atrazine @1.0 kg ha at 1 DAS (PE) followed by tembotrione @120 g/ha(PoE) at 25 DAS	0.60	0.31	0.33	0.40

Table 2: Effect of weed control treatments on crop resistance index at different crop stages.

Treatment	25 DAS	50 DAS	75 DAS	Harvest
Weedy check	1.00	1.00	1.00	1.00
Hand weeding at 20 and 40 days after sowing (DAS)	25.91	9.39	10.96	11.80
Atrazine @ 1.0 kg/ha as pre-emergence (PE) at 1 DAS	19.05	5.05	6.03	4.80
Atrazine @ 750 g/ha + pendimethalin @ 750 g/ha as pre-emergence at 1 DAS	16.19	8.55	7.37	6.72
Atrazine @ 750 g/ha + 2,4-D Amine salt @ 400 g/ha as post emergence (PoE) at 25 DAS	1.48	9.16	10.58	8.70
Halosulfuron @ 60 g/ha(PoE) at 25 DAS	1.21	2.01	2.44	3.20
Atrazine @ 1.0 kg/ha at 1 DAS (PE) followed by halosulfuron @ 60 g/ha (PoE) at 25 DAS	20.86	6.85	6.79	5.79
Tembotrione @ 120 g/ha (PoE) at 25 DAS	1.14	2.04	2.55	2.31
Pendimethalin @1.0 kg/ha at 1 DAS (PE) followed by atrazine @ 750 g/ha + 2,4-D amine salt @ 400 g/ha (PoE) at 25 DAS	12.10	0.19	8.44	7.88
Atrazine @ 1.0 kg/ha at 1 DAS (PE) followed by tembotrione @ 120 g/ha (PoE) at 25 DAS	17.77	11.13	9.90	8.42

Table 3: Weed management index, agronomic weed management index and integrated weed management index as influenced by weed management treatments in hybrid maize.

Treatments	Weed management index		Agronomic weed management index		Integrated weed management index	
	50 DAS	75 DAS	50 DAS	75 DAS	50 DAS	75 DAS
Weedy check	0.00	0.00	0.00	0.00	0.00	0.00
Hand weeding at 20 and 40 days after sowing (DAS)	0.50	0.51	-0.50	-0.49	0.00	0.01
Atrazine @ 1.0 kg/ha as pre-emergence (PE) at 1 DAS	0.39	0.39	-0.61	-0.61	-0.11	-0.11
Atrazine @ 750 g/ha + pendimethalin @ 750 g/ha as pre-emergence at 1 DAS	0.63	0.65	-0.40	-0.35	0.11	0.15
Atrazine @ 750 g/ha + 2,4-D Amine salt @ 400 g/ha as post emergence (PoE) at 25 DAS	0.53	0.59	-0.47	-0.41	0.03	0.09
Halosulfuron @ 60 g/ha(PoE) at 25 DAS	0.14	0.13	-0.86	-0.87	-0.36	-0.37
Atrazine @ 1.0 kg/ha at 1 DAS (PE) followed by halosulfuron @ 60 g/ha (PoE) at 25 DAS	0.43	0.45	-0.57	-0.59	-0.07	-0.07
Tembotrione @ 120 g/ha (PoE) at 25 DAS	0.25	0.25	-0.75	-0.75	-0.25	-0.25
Pendimethalin @1.0 kg/ha at 1 DAS (PE) followed by atrazine @ 750 g/ha + 2,4-D amine salt @ 400 g/ha (PoE) at 25 DAS	0.47	0.47	-0.53	-0.53	-0.03	-0.03
Atrazine @ 1.0 kg/ha at 1 DAS (PE) followed by tembotrione @ 120 g/ha (PoE) at 25 DAS	0.58	0.59	-0.42	-0.41	0.08	0.09

Table 4: Grain yield, stover yield and weed index as influenced by weed control treatments.

Treatment	Grain yield (t/ha)	Stover yield (t/ha)	Weed index
Weedy check	4.49	5.79	35.89
Hand weeding at 20 and 40 days after sowing (DAS)	6.47	7.27	7.57
Atrazine @ 1.0 kg/ha as pre-emergence (PE) at 1 DAS	5.85	6.96	16.45
Atrazine @750 g/ha+ pendimethalin @ 750 g/ha as pre-emergence at 1 DAS	7.00	7.57	0.00
Atrazine @ 750 g/ha + 2,4-D Amine salt @ 400 g/ha as post emergence (PoE) at 25 DAS	6.57	7.40	6.14
Halosulfuron @ 60 g/ha(PoE) at 25 DAS	4.77	6.80	31.80
Atrazine @1.0 kg/ha at 1 DAS (PE) followed by halosulfuron @ 60 g/ha(PoE) at 25 DAS	6.10	7.03	12.92
Tembotrione @ 120 g/ha (PoE) at 25 DAS	5.03	6.77	28.13
Pendimethalin @1.0kg/ha at 1 DAS (PE) followed by atrazine @ 750 g/ha + 2,4-D amine salt @ 400 g/ha (PoE) at 25 DAS	6.26	7.41	10.57
Atrazine @ 1.0 kg/ha at 1 DAS (PE) followed by tembotrione @120 g/ha (PoE) at 25 DAS	6.74	7.53	3.72
SE(m)±	0.35	0.26	-
CD (P = 0.05)	1.05	0.77	-

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