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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(4): 1120-1125

www.thepharmajournal.com
Received: 11-01-2023
Accepted: 27-02-2023

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Pre-emergence herbicidal effect of nano atrazine on growth parameters of maize in south Gujarat condition

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Abstract
A field experiment was conducted at college farm, N. M. College of Agriculture, Navsari Agricultural University, Navsari (Gujarat) during *rabi* and summer seasons of 2021 and 2022 respectively to study the effect of nano atrazine treatments on some growth characteristics of maize. The experiment was laid out in a Randomized Block Design (RBD) having ten treatments with three replications and the treatments include *viz*., T_1: recommended atrazine dose (1 kg ai ha^{-1}), T_2: nano-atrazine at 100% RDPE, T_3: nano-atrazine at 87.5% RDPE, T_4: nano-atrazine at 75.0% RDPE, T_5: nano atrazine at 50.0% RDPE, T_6: nano-atrazine at 87.5% RDPE + 2,4-D PoE, T_7: nano atrazine at 75% RDPE + 2,4-D PoE, T_8: nano-atrazine at 50% RDPE + 2,4-D PoE, T_9: weed free, T_{10}: unweeded. The growth parameters *viz*., plant height, dry biomass, number of leaves $plant^{-1}$, leaf area $plant^{-1}$, crop growth rate and relative growth rate were observed maximum under weed free treatment (T_9) followed by T_1 (Recommended atrazine dose (1 kg a.i. ha^{-1}), T_6 (Nano atrazine at 87. 5% RDPE + 2,4-D PoE) and T_2 (Nano atrazine at 100% RDPE). Emphasizing on farmers and finding an eco-friendly alternative for weed management treatment T_6 (Nano atrazine at 87. 5% RDPE + 2,4-D PoE) would be recommended, and additional studies should be conducted in the near future.

Keywords: Pre-emergence, herbicidal, nano, parameters, maize

Introduction
The rise in global population, combined with improved income and dietary changes, is driving an ever-increasing food demand that is expected to rise by 70% in 2050 (FAO, 2009) [3]. The increase in population growth was due to several factors such as a reduction in the rate of mortality due to improved sanitation, medical facilities and a huge increase in productivity in the agricultural sector by green revolution. But with increasing population and shrinking resources, it would be a great challenge to maintain food security for both developing and developed countries. Furthermore, agricultural crop pests including weeds, diseases, pathogens, climate change events such as drought, and low nutrient use efficiency are significant hindrances in achieving global food security. Weeds are the major cause of economic loss in crop production and mainly in maize crop. Maize is a widely grown cereal after rice and wheat and contributes almost 5% to the global dietary supply. It is an emerging cash crop, because of its high yield potentiality and also the favourable climatic conditions which allow maize production round the year.
In today's world, chemical weeding is being widely accepted due to the uneconomical labor required for physical weeding methods. On the other hand, the unbalanced use of chemicals has led to harsh conditions for the environment, consequently minimizing the yield of crops and soil productivity. Although herbicides have many side effects, their use cannot be discontinued due to their usefulness in increasing the yield of different crops to meet the food demand of the ever-growing human population Therefore, innovative technology needs to be devised in order to minimize the use of these harmful chemicals for the preferential growth of the desired species.
Nanotechnology has emerged as a field with promising applications in agriculture, including the development of nano devices for the delivery of genes, fertilizers, phytohormones, and plant protection products (de Oliveira *et al.*, 2015) [2]. A variety of formulations based on nanoparticles have been produced as carrier systems for pesticides, enabling slow release of the active ingredient and extension of its duration of action.

In addition to, nano herbicide is a target-specific herbicide molecule encapsulated with nanoparticle and has aimed for specific receptor in the roots of target weeds, which enter into root system and translocated to parts that inhibit glycolysis of food reserve in the root system. Hence, to achieve the best results, a coherent approach and agronomic intervention are required for better study of nano atrazine.

Materials and Methods

In order to attain the objectives, the experiment was carried out at two different locations, A Block in rabi season of 2021 and repeated in ensuing summer season of 2022 in Block B of College Farm, N. M. College of Agriculture, Navsari Agricultural University, Navsari. The experiment was laid-out in randomized block design with 10 treatments and replicated thrice. The treatments were comprises of T_1: Recommended atrazine dose (1 kg ai ha^{-1}), T_2: Nano atrazine at 100% RDPE, T_3: Nano atrazine at 87.5% RDPE, T_4: Nano atrazine at 75.0% RDPE, T_5: Nano atrazine at 50.0% RDPE, T_6: Nano atrazine at 87.5% RDPE + 2,4-D PoE, T_7: Nano atrazine at 75.0% RDPE + 2,4-D PoE, T_8: Nano atrazine at 50.0% RDPE + 2,4-D PoE, T_9: Weed free, T_{10}: Unweeded. In this experiment, nano atrazine of different concentrations was applied to the plots as pre-emergence and 2,4- D was applied as post emergence at 25 DAS. Herbicides were applied with the help of knapsack sprayer fitted with flat fan T-jet nozzle using a spray volume of 500 L ha^{-1}. The nitrogen was applied through urea (46% N) in two splits, first half is applied as basal dose and remaining half applied at 30 DAS. Whereas, phosphorus was applied through single superphosphate (16% P_2O_5). For all the growth and development studies during the crop growth period five plants were selected randomly and were tagged in each plot where plants from border rows were selected for recording observations. Various growth parameters were recorded at 30 days interval in maize. The leaves of randomly selected plant cut out to measure its length and breadth. The length × breadth was multiplied and the product of it again multiplied with total green leaves $plant^{-1}$. Since, the length and breadth of leaf are not same from base to tip of leaf. The multiplication/correction factor of 0.75 was used to calculate the total leaf area $plant^{-1}$. Plant samples for dry matter accumulation were taken from the second or the penultimate row at different stages by clipping the plants close to the soil surface from each plot. They were sundried and thereafter shifted in the oven to dry at a temperature of 65±5 °C till a constant weight was achieved and dry matter accumulation was recorded which was expressed as dry weight in g $plant^{-1}$. The dry matter accumulation by plant was calculated at 30, 60, 90 DAS and harvest. The increase in plant material per unit time or cumulative crop growth rate (CGR) was calculated as per the formula given by Radford (1967) [6] and was expressed as g m^{-2} day^{-1}.

$$\text{Crop growth rate (CGR)} = \frac{1(W_2 - W_1)}{P\,(t_2 - t_1)}$$

Where,
W_1=Total dry matter of crop plant at the time interval t_1
W_2=Total dry matter of crop plant at the time interval t_2
P= Ground cover area

The relative growth rate of crop (RGR) was calculated as per the formula given by Radford (1967) [6] which was expressed as g g^{-1} day^{-1}.

$$\text{Relative growth rate (RGR)} = \frac{(\text{Log e } W_2 - \text{Log e } W_1)}{(t_2 - t_1)}$$

Where,
W_1=Total dry matter of crop plant at the time interval t_1
W_2=Total dry matter of crop plant at the time interval t_2

Statistical Analysis

The data on various variables were analyzed by using statistical procedures as described by Panse and Sukhatme (1967) [5]. The treatment effects on all the characters under study were computed with ANOVA by employing design Randomized Block Design. The critical difference (CD) at 5% was calculated where differences among the treatments were found significant in 'F' test, otherwise only standard error of mean was calculated. The co-efficient of variation was also worked out for all the characters and presented. Simple technique of analysis of variance may not be valid under two different seasonal conditions as the error variances in the seasons and the treatment x season interaction may be significant. Hence, pooled analysis of the maize crop analyzed for two years was worked out as per the method described by Panse and Sukhatme (1967) [5]. Bartlett's test was applied to examine the homogeneity of variance due to error. The variance obtained due to season x treatment components were tested against joint estimate of error variance with an objective to find out whether season x treatment interaction exist or otherwise.

Results and Discussion

Plant Height

The data pertaining to plant height at 30, 60, 90 DAS and at harvest as influenced by different nano atrazine treatments is presented in Table 1. It can be observed that plant height increased with the advancing of crop growth stages and was found highest at the time of harvest. An appraisal of data in Table 1. stated that significant differences in plant height was observed at 30, 60, 90 DAS and at harvest due to various nano atrazine treatments during individual years and in pooled results. At 30, 60, 90 DAS and at harvest higher plant height was recorded in weed free treatment T_9 during both the years and in pooled results. Which was found statistically at par with treatments T_1 (Recommended atrazine dose (1 kg *a.i.* ha^{-1})), T_6 (Nano atrazine at 87. 5% RDPE + 2,4-D PoE) and T_2 (Nano atrazine at 100% RDPE) in both the years and remained statistically superior over treatment T_{10} (unweeded) and remaining other treatments.

Table 1: Plant height (cm) of maize at 30, 60, 90 DAS and at harvest as influenced by different nano atrazine treatments

Treatment	30 DAS			60 DAS			90 DAS			At harvest		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T_1: Recommended atrazine dose (1 kg *a.i.* ha^{-1})	48.28	45.69	46.99	157.48	154.47	155.98	186.34	175.77	181.06	197.36	186.15	191.75
T_2: Nano atrazine at 100% RDPE	47.97	45.02	46.50	149.61	142.90	146.25	176.00	167.74	171.87	186.21	177.51	181.86
T_3: Nano atrazine at 87.5% RDPE	45.17	43.87	44.52	144.08	139.03	141.56	171.25	160.79	166.02	181.38	170.30	175.84
T_4: Nano atrazine at 75.0% RDPE	43.06	40.71	41.89	138.75	130.47	134.61	166.50	156.64	161.57	176.15	165.79	170.97
T_5: Nano atrazine at 50.0% RDPE	40.21	37.67	38.94	133.35	131.84	132.60	155.84	145.54	150.69	165.03	154.15	159.59
T_6: Nano atrazine at 87. 5% RDPE + 2,4-D PoE	45.76	43.32	44.54	153.23	152.95	153.09	180.05	169.98	175.01	190.64	179.99	185.32
T_7: Nano atrazine at 75.0% RDPE + 2,4-D PoE	43.36	40.97	42.17	141.78	136.47	139.12	169.51	159.38	164.44	179.55	168.80	174.18
T_8: Nano atrazine at 50.0% RDPE + 2,4-D PoE	40.26	37.77	39.02	137.06	131.90	134.48	159.71	150.62	155.16	169.02	159.41	164.22
T_9: Weed free	51.60	48.45	50.02	162.33	159.10	160.72	195.58	186.38	190.98	207.08	197.38	202.23
T_{10}: Unweeded	37.88	33.89	35.88	128.98	127.57	128.27	128.66	127.35	128.00	137.70	133.68	135.69
S.Em+	2.70	2.65	1.89	6.86	7.29	5.01	9.08	8.34	6.16	8.41	9.07	6.18
CD (P=0.05)	8.02	7.87	5.43	20.39	21.66	14.36	26.98	24.77	17.68	24.99	26.94	17.74
CV (%)	10.55	11.00	10.77	8.22	8.98	8.60	9.31	9.02	9.18	8.14	9.28	8.70
Interaction (S x T)												
S.Em+			1.892			7.07			8.71			8.74
CD (P=0.05)			NS			NS			NS			NS

Number of Leaves Plant^{-1}

The observations related to number of leaves plant^{-1} recorded at 30, 60, 90 DAS and at harvest as influenced by different nano atrazine treatments are presented in Table 2. The effect of different nano atrazine treatments on number of leaves plant^{-1} at 30 DAS did not cause any significant effect on number of leaves. However, it was highest with treatment T_9 (weed free) and recorded lowest in the treatment T_{10} (Unweeded).

However, at 60 DAS (12.46, 11.26 and 11.86), at 90 DAS (14.78, 13.53 and 14.16) and at harvest (15.89, 14.16 and 15.03), treatment T_9 (weed free) produced significantly higher number of leaves plant^{-1} during both the years and in pooled analysis. However, in individual years and in pooled analysis, the treatment T_{10} (Unweeded) had a lower number of leaves plant^{-1} at all the stages of crop growth.

Table 2: Number of leaves of maize at 30, 60, 90 DAS and at harvest as influenced by different nano atrazine treatments

Treatment	30 DAS			60 DAS			90 DAS			At harvest		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T_1: Recommended atrazine dose (1 kg *a.i.* ha^{-1})	5.90	5.60	5.75	11.63	10.43	11.03	13.85	12.57	13.21	14.87	13.20	14.03
T_2: Nano atrazine at 100% RDPE	5.53	5.35	5.44	11.26	10.06	10.66	13.48	12.18	12.83	14.47	12.81	13.64
T_3: Nano atrazine at 87.5% RDPE	5.40	5.20	5.30	10.91	9.72	10.32	12.82	11.49	12.15	13.76	12.12	12.94
T_4: Nano atrazine at 75.0% RDPE	5.27	4.90	5.08	10.46	9.26	9.86	12.68	11.35	12.02	13.62	11.98	12.80
T_5: Nano atrazine at 50.0% RDPE	4.90	4.63	4.77	9.73	8.56	9.15	11.95	10.59	11.27	12.85	11.22	12.03
T_6: Nano atrazine at 87. 5% RDPE + 2,4-D PoE	5.82	5.53	5.68	11.43	10.26	10.85	13.65	12.36	13.00	14.65	12.99	13.82
T_7: Nano atrazine at 75.0% RDPE + 2,4-D PoE	5.40	5.13	5.27	10.86	9.66	10.26	12.77	11.44	12.10	13.71	12.07	12.89
T_8: Nano atrazine at 50.0% RDPE + 2,4-D PoE	5.07	4.78	4.93	10.13	8.93	9.53	12.35	11.00	11.68	13.27	11.63	12.45
T_9: Weed free	6.07	5.78	5.93	12.46	11.26	11.86	14.78	13.53	14.16	15.89	14.16	15.03
T_{10}: Unweeded	4.80	4.40	4.60	9.40	8.20	8.80	11.61	10.24	10.93	12.50	10.87	11.68
S.Em+	0.46	0.42	0.31	0.51	0.50	0.36	0.65	0.62	0.45	0.65	0.62	0.45
CD (P=0.05)	NS	NS	NS	1.51	1.49	1.02	1.93	1.84	1.29	1.93	1.84	1.29
CV (%)	14.62	14.13	14.40	8.11	9.00	8.53	8.66	9.21	8.92	8.05	8.74	8.38
Interaction (S x T)												
S.Em+			0.43			0.50			0.63			0.63
CD (P=0.05)			NS			NS			NS			NS

Leaf Area Plant^{-1} (cm^2): Data pertaining to leaf area plant^{-1} as influenced by different nano atrazine treatments are provided in Table 3. The leaf area of maize is a direct indicator of net photosynthesis which exposed significant influence (leaf area plant^{-1}) due to different treatments at 30, 60 and 90 DAS during the individual years and in pooled analysis. At 30 DAS, maximum leaf area of 983.35 cm^2 plant^{-1} was recorded under weed free treatment (T_9), followed by T_1 (Recommended atrazine dose (1 kg *a.i.* ha^{-1})), T_2 (Nano atrazine at 100% RDPE), T_6 (Nano atrazine at 87.5% RDPE + 2,4-D PoE) and T_3 (Nano atrazine at 87.5% RDPE) and remained statistically superior over unweeded treatment (T_{10}). It was evident from the data given in Table 3. that at 60 DAS weed free treatment (T_9) recorded maximum leaf area (3323.01, 3085.17, 3204.09 cm^2 plant^{-1} respectively) during both the years and as well as in pooled results and which was found statistically at par with treatments T_1 (Recommended atrazine dose (1 kg *a.i.* ha^{-1})), T_6 (Nano atrazine at 87.5% RDPE + 2,4-D PoE) and T_2 (Nano atrazine at 100% RDPE) during both the years and remained statistically superior over (T_{10}) unweeded and other remaining treatments. But in pooled result only treatments T_1 (Recommended atrazine dose (1 kg *a.i.* ha^{-1})) and T_6 (Nano atrazine at 87.5% RDPE + 2,4-D PoE) remained statistically at par with treatment (T_9) and superior over unweeded (T_{10}) and other remaining treatments. Similar line of performance by treatments was observed at 90 DAS (4444.96, 4232.62, 4338.79 cm^2 plant^{-1} respectively) and at harvest (4506.05, 4474.07, 4490.06 cm^2 plant^{-1} respectively) and the data recorded revealed that weed free treatment (T_9) recorded maximum leaf area and treatment (T_{10}) recorded minimum leaf area during both the years and as well as in pooled results.

Table 3: Leaf area plant^{-1} (cm^2) of maize at 30, 60, 90 DAS and at harvest as influenced by different nano atrazine treatments

Treatment	30 DAS			60 DAS			90 DAS			At harvest		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T_1: Recommended atrazine dose (1 kg *a.i.* ha^{-1})	931	762	846	3079	2841	2960	4201	3988	4094	4324	4188	4256
T_2: Nano atrazine at 100% RDPE	926	757	841	2858	2620	2739	3980	3767	3873	4096	3960	4028
T_3: Nano atrazine at 87.5% RDPE	882	712	797	2634	2397	2515	3756	3544	3650	3890	3753	3821
T_4: Nano atrazine at 75.0% RDPE	849	679	764	2420	2182	2301	3542	3329	3436	3665	3529	3597
T_5: Nano atrazine at 50.0% RDPE	804	634	719	2204	1966	2085	3326	3113	3220	3459	3323	3391
T_6: Nano atrazine at 87. 5% RDPE + 2,4-D PoE	891	722	807	2931	2694	2812	4053	3841	3947	4159	4022	4090
T_7: Nano atrazine at 75.0% RDPE + 2,4-D PoE	853	684	769	2504	2267	2386	3626	3414	3520	3773	3637	3705
T_8: Nano atrazine at 50.0% RDPE + 2,4-D PoE	805	635	720	2298	2060	2179	3420	3208	3314	3544	3408	3476
T_9: Weed free	983	814	899	3323	3085	3204	4445	4233	4339	4506	4474	4490
T_{10}: Unweeded	767	597	682	1962	1724	1843	3084	2871	2978	3182	3046	3114
S.Em+	42.60	42.60	30.12	172.90	169.81	121.17	201.85	201.85	142.73	182.88	199.62	135.37
CD (P=0.05)	126.58	126.58	86.40	513.70	504.52	347.53	599.73	599.73	409.37	543.37	593.12	388.25
CV (%)	8.49	10.55	9.41	11.42	12.34	11.86	9.34	9.90	9.61	8.21	9.26	8.73
Interaction (S x T)												
S.Em+			42.60			171.35			201.85			191.43
CD (P=0.05)			NS			NS			NS			NS

Dry matter Accumulation (g plant^{-1})

It was evident from the data that dry matter accumulation plant^{-1} increased progressively with the advancement of crop growth stages. During both the years as well as in pooled analysis, different treatments exhibited significant variation in dry matter accumulation plant^{-1} at each stage of data recorded and mentioned in Table 4.

At 30 DAS dry matter accumulation plant^{-1} was influenced significantly by nano atrazine treatments and recorded significantly maximum dry matter accumulation plant^{-1} in treatment (T_9) (34.67, 33.00, 33.83 g plant^{-1}) during both the years and in pooled result, respectively and which was found statistically at par with treatments T_1 (Recommended atrazine dose (1 kg *a.i.* ha^{-1})), T_6 (Nano atrazine at 87.5% RDPE + 2,4-D PoE) and T_2 (Nano atrazine at 100% RDPE) in the first year and as well as in pooled result while in second year treatment T_3 (Nano atrazine at 87.5% RDPE) along with treatments T_1 (Recommended atrazine dose (1 kg *a.i.* ha^{-1})), T_6 (Nano atrazine at 87.5% RDPE + 2,4-D PoE) and T_2 (Nano atrazine at 100% RDPE) found at par with weed free treatment and remained significantly superior over unweeded (T_{10}) and other remaining treatments. Similar results were recorded at 60 DAS during both the years as well as in pooled. However, at 90 DAS (155.33, 148.33, 53.33, 151.83 g plant^{-1}) and at harvest (187.88, 179.67, 183.78 g plant^{-1}) observation demonstrated that treatment weed free (T_9) recorded maximum plant dry matter accumulation which remained statistically at par with treatments T_1 (Recommended atrazine dose (1 kg *a.i.* ha^{-1})) followed by T_6 (Nano atrazine at 87.5% RDPE + 2,4-D PoE) and T_2 (Nano atrazine at 100% RDPE) and significantly superior over rest of the treatments during both the years.

Table 4: Dry matter of maize (g plant^{-1}) at 30, 60, 90 DAS and at harvest as influenced by different nano atrazine treatments

Treatment	30 DAS			60 DAS			90 DAS			At harvest		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T_1: Recommended atrazine dose (1 kg *a.i.* ha^{-1})	33.33	32.00	32.67	90.00	79.67	84.83	149.33	143.67	146.50	177.67	169.33	173.50
T_2: Nano atrazine at 100% RDPE	30.33	30.67	30.50	80.33	73.67	77.00	136.77	129.21	132.99	166.67	159.33	163.00
T_3: Nano atrazine at 87.5% RDPE	28.33	27.33	27.83	78.33	72.00	75.17	124.67	119.33	122.00	153.33	147.33	150.33
T_4: Nano atrazine at 75.0% RDPE	26.44	25.33	25.89	66.67	60.67	63.67	112.67	105.67	109.17	139.67	130.33	135.00
T_5: Nano atrazine at 50.0% RDPE	25.33	23.67	24.50	59.67	52.33	56.00	101.67	96.33	99.00	134.33	127.67	131.00
T_6: Nano atrazine at 87. 5% RDPE + 2,4-D PoE	32.33	31.67	32.00	83.33	77.00	80.17	142.33	135.67	139.00	172.67	164.33	168.50
T_7: Nano atrazine at 75.0% RDPE + 2,4-D PoE	27.67	26.33	27.00	72.33	67.67	70.00	119.67	114.00	116.83	149.67	143.67	146.67
T_8: Nano atrazine at 50.0% RDPE + 2,4-D PoE	26.00	23.67	24.83	63.33	60.33	61.83	105.33	96.67	101.00	138.67	133.67	136.17
T_9: Weed free	34.67	33.00	33.83	94.33	85.33	89.83	155.33	148.33	151.83	187.88	179.67	183.78
T_{10}: Unweeded	23.40	21.67	22.54	56.00	50.67	53.33	89.67	81.67	85.67	121.67	113.67	117.67
S.Em+	1.92	2.02	1.39	4.42	4.07	3.00	6.47	6.68	4.65	8.12	7.56	5.55
CD (P=0.05)	5.70	6.01	4.00	13.13	12.10	8.62	19.24	19.85	13.34	24.14	22.46	15.91
CV (%)	11.54	12.73	12.13	10.29	10.38	10.34	9.06	9.89	9.46	9.13	8.91	9.03
Interaction (S x T)												
S.Em+			1.97			4.24			6.57			7.84
CD (P=0.05)			NS			NS			NS			NS

Crop Growth Rate (CGR)

A critical examination of the data recorded periodically at 30-60, 60- 90 and 90-120 DAS and presented in Table 5. showed that CGR was significantly influenced by different nano atrazine treatments.

At 0-30 DAS data presented in Table 5. indicated that weed free treatment (T_9) recorded significantly higher crop growth rate(1.16, 1.10 and 1.13 g m^{-2} day^{-1} during 2021, 2022 and on pooled basis, respectively) and it was found to be at par with treatment T_1 (Recommended atrazine dose (1 kg *a.i.* ha^{-1})), T_6 (Nano atrazine at 87.5% RDPE + 2,4-D PoE) and T_2 (Nano atrazine at 100% RDPE) in the first year and as well as in pooled result while in second year treatment T_3 (Nano atrazine at 87.5% RDPE) along with treatments T_1 (Recommended atrazine dose (1 kg *a.i.* ha^{-1})), T_6 (Nano atrazine at 87.5% RDPE + 2,4-D PoE) and T_2 (Nano atrazine at 100% RDPE) found at par with weed free treatment and remained significantly superior over unweeded (T_{10}) and other remaining treatments.

At 30-60 (1.99, 1.74 and 1.87 g m^{-2} day^{-1}), 60-90 (2.09, 2.05 and 2.07 g m^{-2} day^{-1}) and 90-120 DAS (1.08, 1.04 and 1.06 g m^{-2} day^{-1}) data presented in Table 5 showed that weed free treatment (T_9) recorded significantly higher crop growth rate during 2021, 2022 and on pooled basis, respectively) and treatments T_1 (Recommended atrazine dose (1 kg *a.i.* ha^{-1})), T_6 (Nano atrazine at 87.5% RDPE + 2,4-D PoE) and T_2 (Nano atrazine at 100% RDPE) found at par with weed free treatment in both the years but in pooled result treatment T_1 (Recommended atrazine dose (1 kg *a.i.* ha^{-1})) only found to be at par with weed free treatment and superior over rest of the treatments. Whereas, unweeded treatment (T_{10}) recorded lowest crop growth rate among all the treatments at all the stages of crop growth. It is also noted that among all the stages of crop growth, CGR was recorded maximum during the mid-stage of the crop growth (60-90 DAS).

Table 5: Crop growth rate of maize at (0- 30 days), (30-60 days), (60-90 days), (90-120 days) as influenced by different nano atrazine treatments

Treatment	0- 30 days			30-60 days			60-90 days			90-120 days		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T_1: Recommended atrazine dose (1 kg *a.i.* ha^{-1})	1.11	1.07	1.09	1.89	1.59	1.74	2.00	1.98	1.99	1.04	1.05	1.05
T_2: Nano atrazine at 100% RDPE	1.06	1.02	1.04	1.69	1.49	1.59	1.83	1.79	1.81	0.94	0.86	0.90
T_3: Nano atrazine at 87.5% RDPE	0.94	0.91	0.93	1.67	1.44	1.55	1.78	1.73	1.76	0.96	0.93	0.95
T_4: Nano atrazine at 75.0% RDPE	0.86	0.84	0.85	1.37	1.18	1.27	1.49	1.45	1.47	0.90	0.82	0.86
T_5: Nano atrazine at 50.0% RDPE	0.82	0.79	0.81	1.17	0.95	1.06	1.36	1.32	1.34	1.09	1.04	1.07
T_6: Nano atrazine at 87. 5% RDPE + 2,4-D PoE	1.08	1.06	1.07	1.70	1.51	1.61	1.85	1.82	1.84	1.01	0.96	0.98
T_7: Nano atrazine at 75.0% RDPE + 2,4-D PoE	0.92	0.88	0.90	1.49	1.38	1.43	1.66	1.61	1.64	1.00	0.99	1.00
T_8: Nano atrazine at 50.0% RDPE + 2,4-D PoE	0.83	0.79	0.81	1.28	1.22	1.25	1.45	1.42	1.43	1.11	1.23	1.17
T_9: Weed free	1.16	1.10	1.13	1.99	1.74	1.87	2.09	2.05	2.07	1.08	1.04	1.06
T_{10}: Unweeded	0.78	0.72	0.75	1.09	0.97	1.03	1.21	1.15	1.18	1.07	1.09	1.08
S.Em+	0.072	0.067	0.049	0.108	0.086	0.069	0.091	0.093	0.065	0.044	0.070	0.041
CD (P=0.05)	0.21	0.20	0.14	0.32	0.26	0.20	0.27	0.28	0.19	0.13	0.21	0.12
CV (%)	13.04	12.73	12.90	12.18	11.10	11.74	9.45	9.87	9.66	7.44	12.10	10.00
Interaction (S x T)												
S.Em+			0.06			0.09			0.09			0.05
CD (P=0.05)			NS			NS			NS			NS

Relative Growth Rate (RGR)

The data presented in the Table 6. revealed that Relative growth rate was not influenced significantly by nano atrazine weed management treatments at all growth stages of maize. However, numerically higher values were recorded in weed free treatment (T_9) at 30-60, (0.0145, 0.0137, 0.0141), 60-90 (0.007, 0.008, 0.008) and 90-120 DAS (0.015, 0.014, 0.014) wherein, unweeded treatment (T_{10}) recorded lowest values during both the years and in pooled analysis, respectively.

Table 6: Relative growth rate of maize at (30-60 days), (60-90 days), (90-120 days) as influenced by different nano atrazine treatments

Treatment	30-60 days			60-90 days			90-120 days		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T1: Recommended atrazine dose (1 kg *a.i.* ha-1)	0.0134	0.0127	0.0130	0.008	0.008	0.008	0.013	0.013	0.013
T2: Nano atrazine at 100% RDPE	0.0144	0.0131	0.0137	0.007	0.009	0.008	0.014	0.013	0.014
T3: Nano atrazine at 87.5% RDPE	0.0149	0.0143	0.0146	0.007	0.007	0.007	0.015	0.014	0.015
T4: Nano atrazine at 75.0% RDPE	0.0140	0.0127	0.0133	0.008	0.008	0.008	0.014	0.013	0.013
T5: Nano atrazine at 50.0% RDPE	0.0129	0.0116	0.0122	0.008	0.009	0.008	0.013	0.012	0.012
T6: Nano atrazine at 87. 5% RDPE + 2,4-D PoE	0.0136	0.0127	0.0132	0.008	0.008	0.008	0.014	0.013	0.013
T7: Nano atrazine at 75.0% RDPE + 2,4-D PoE	0.0139	0.0136	0.0138	0.007	0.007	0.007	0.014	0.014	0.014
T8: Nano atrazine at 50.0% RDPE + 2,4-D PoE	0.0133	0.0135	0.0134	0.008	0.007	0.007	0.013	0.013	0.013
T9: Weed free	0.0145	0.0137	0.0141	0.007	0.008	0.008	0.015	0.014	0.014
T10: Unweeded	0.0126	0.0123	0.0125	0.007	0.007	0.007	0.013	0.012	0.012
S.Em+	0.0008	0.0007	0.0005	0.001	0.001	0.000	0.001	0.001	0.001
CD (P=0.05)	0.0024	0.0020	0.0015	0.002	0.002	0.001	0.003	0.004	0.002
CV (%)	10.17	8.76	9.53	12.273	11.329	11.787	13.034	16.897	14.990
Interaction (S x T)									
S.Em+			0.0007			0.0005			0.0011
CD (P=0.05)			NS			NS			NS

Discussion

In a nutshell, nano atrazine herbicides treatments along with cultural practices included in the study were found to be effective in managing the weeds which in turn provided congenial condition to the crop for better utilization of available resources leading to increased plant height as compared to unweeded (T_{10}) treatment at 30, 60, 90 DAS and at harvest. There was a sharp increase in plant height, number of leaves plant^{-1}, leaf area plant^{-1} and dry matter accumulation from initial stage of crop growth and long stature plants, higher number of leaves plant^{-1}, leaf area plant^{-1} and dry matter accumulation had been observed in weed free (T_9) treatment and it might be due to the fact that weed free conditions due to management of weeds had provided enough light, space and nutrients which resulted in increased growth attributing characters in maize crop. Similar results were reported by Kannur *et al.* (2008) [4]. Better growth parameters were noticed probably due to effective control of weeds, owing to reduced crop weed competition during the crop growth stages which in turn resulted in rapid cell multiplication and elongation, leading to increase in internodal length. These results are in conformity with findings of Abdullahi *et al.* (2016) [1].

Conclusion

It may be concluded from the study that all the nano atrazine treatments were efficient in controlling weed and resulted in better performances of plant growth. Further, various morphological parameters were studied and it was noticed that treatment T_9 (Weed free) recorded significantly higher number of leaves plant^{-1}, leaf area plant^{-1} and dry matter accumulation plant^{-1} over T_{10} (unweeded) treatment and was remained statistically at par with treatments T_1 (Recommended atrazine dose (1 kg *a.i.* ha^{-1})) followed by T_6 (Nano atrazine at 87. 5% RDPE + 2,4-D PoE) and T_2 (Nano atrazine at 100% RDPE) at different growth intervals during both the year as well as in pooled analysis.

Acknowledgement

The authors are grateful to the Vice Chancellor NAU, Navsari, to provide the necessary facilities and financial assistance for carrying out this study.

Conflict of interest

All the authors here by declares that no conflict of interest is involved with this research work.

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