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Optimizing time and dose of newly synthesised Nano encapsulated sulfentrazone herbicide formulation for weed management in irrigated groundnut (*Arachis hypogaea*)

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Abstract
Field experiment was carried out in the Eastern Block Farms, Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore, to optimize the time and dose of newly synthesised nano encapsulated sulfentrazone herbicide formulation for weed management in irrigated groundnut during summer season of 2021. Two doses of sulfentrazone herbicides (0.30 kg ha^{-1} and 0.40 kg ha^{-1}) with or without encapsulation applied one day before sowing, one, two and three days after sowing. The treatments were compared with absolute control, replicated thrice and laid out in randomized block design. The study revealed that the lower weed dry weight and weed control index were achieved with the plot applied with encapsulated sulfentrazone one day before sowing at the rate of 0.30 kg ha^{-1} compared to control. The same treatment registered higher pod and haulm yields. Higher weed dry weight, weed density and the least pod yield was observed with the absolute control. Application of sulfentrazone at the rate of 0.40 kg ha^{-1} recorded phytotoxic symptoms during the initial period of crop growth.

Keywords: Herbicide, sulfentrazone, nano encapsulation, groundnut, phytotoxicity, weed density, weed dry weight, weed control index

Introduction
Groundnut (*Arachis hypogaea* L.), the "King of Oilseeds" is one of the most important and edible oilseed crops in the world. In Indian scenario, groundnut is grown throughout the year in *Kharif*, *Rabi*, summer and spring seasons in one or other parts of the country. Seventy per cent of total annual world production of unshelled nuts is contributed by India, China and U.S.A. (El Naim *et al*., 2010) [4]. Groundnut is an excellent source of nutrients containing 45–50% oil, 27–33% protein as well as essential minerals and vitamins. The yield of groundnut depends more on agronomic management factors and the reason for low productivity of groundnut is mainly due to weed infestation. Groundnut or peanut is highly susceptible to weed infestation because of its slow growth in the initial stages up to 45 DAS with short plant height and underground pod bearing habit. Weeds in groundnut not only compete for nutrients, soil moisture, sunlight but also inhibit pegging, pod development and also interfere with harvest. Weed interference resulted in yield loss ranging from 74 to 92% (Agostinho *et al.*, 2006) [1]. The critical period of crop weed competition ranged from four to nine weeks. Weed competition persists even in later stages of crop period which leads to severe yield loss due to disturbance of soil by hand weeding or hoeing at peg penetration and pod development stages. So, once peg formation has begun, manual or mechanical weed control methods should not be practised. Thus, herbicides offer the most effective means for the control of weeds among different weed management methods and it is easy, time saving method when compared to hand weeding and they are the only alternatives left under the circumstances of unavailability of labourers and high cost labourers. The critical period of weed control would help in controlling the early season weeds but the escaped and flushes of late season weeds lead to yield losses and also add weed seeds to soil which could make serious problems in subsequent cropping seasons. So weed management throughout the crop season can be made possible with the help of advanced technologies like nanotechnology.

Low dose herbicides with slow releasing nature can bring effective control of weeds with reasonable doses non-toxic to crops, persistence throughout growing season and leaving no residue at the end of the season permitting subsequent crops in the sequence (Bommayasamy *et al*., 2018) [2]. Sulfentrazone is a new herbicidal molecule belonging to the family of phenyl triazolinone which controls the weeds by the process of protoporphyrinogen oxidase inhibition (membrane disruption), commonly referred to as PPO inhibition. It can be applied as pre plant, pre-emergence or post-emergence for broad spectrum control of weeds (Dayan *et al*., 1996) [3]. Hence new attempt at use of sulfentrazone for groundnut has been made with the help of encapsulation using polymers.

Materials and Methods

The field experiment was carried out in Eastern block farms, Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore during summer 2021. The farm is geographically located at a latitude of 11 0' 54" N, longitude of 76 56'4'' E and at an altitude of 426.7 m above mean sea level (MSL). The soil of the experimental field was sandy clay loam in texture with 0.48% organic carbon, low in available nitrogen (176 kg ha^{-1}), high in available phosphorus (28 kg ha^{-1}) and available potassium (570 kg ha^{-1}).

Laboratory experiment

The process of enclosing the active ingredients with materials like polymers is called encapsulation. Nano encapsulation of sulfentrazone herbicide was done by solvent evaporation method in PG laboratory in the Department of Agronomy. A known quantity of herbicide (48% SL) and ultrapure water were first mixed and stirred for five minutes using magnetic stirrer @ 600-1200 rpm. Then solvent (methanol) and polymer (poly ethylene glycol) were mixed in a separate container and stirred for 5 minutes. After then both the solutions were mixed and stirred for 5-10 minutes. This constituted organic phase. Then four percent starch solution (aqueous phase) was prepared and stirred for an hour. Finally organic phase was added to aqueous phase (1:1 ratio of sulfentrazone and starch solution) drop by drop and stirred for 12 hours using magnetic stirrer. Thus formed nanoencapsulated sulfentrazone herbicide formulation was characterized in the particle size analyzer (PSA) and used for field trials.

Field experiment

The experiment was laid out in randomized block design and replicated thrice. The treatments included were Sulfentrazone 0.30 kg ha^{-1} e^+ at 1 DBS (T_1), Sulfentrazone 0.30 kg ha^{-1} e^+ at 1 DAS (T_2), Sulfentrazone 0.30 kg ha^{-1} e^+ at 2 DAS (T_3), Sulfentrazone 0.30 kg ha^{-1} e^+ at 3 DAS (T_4), Sulfentrazone 0.40 kg ha^{-1} e^+ at 1 DBS (T_5) Sulfentrazone 0.40 kg ha^{-1} e^+ at 1 DAS (T_6), Sulfentrazone 0.40 kg ha^{-1} e^+ at 2 DAS (T_7), Sulfentrazone 0.40 kg ha^{-1} e^+ at 3 DAS (T_8), Sulfentrazone 0.30 kg ha^{-1} e^- at 1 DBS (T_9), Sulfentrazone 0.30 kg ha^{-1} e^- at 1 DAS (T_{10}), Sulfentrazone 0.30 kg ha^{-1} e^- at 2 DAS (T_{11}), Sulfentrazone 0.30 kg ha^{-1} e^- at 3 DAS (T_{12}), Sulfentrazone 0.40 kg ha^{-1} e^- at 1 DBS (T_{13}), Sulfentrazone 0.40 kg ha^{-1} e^- at 1 DAS(T_{14}), Sulfentrazone 0.40 kg ha^{-1} e^- at 2 DAS(T_{15}),, Sulfentrazone 0.40 kg ha^{-1} e^- at 3 DAS(T_{16}), Absolute control (T_{17}) (e^+ - with encapsulation; e^- - without encapsulation; DBS: Day Before Sowing; DAS: Days After Sowing).

The recommended dose of fertilizer for irrigated groundnut was applied (25:50:75 kg of N:P:K ha^{-1}) through urea, single super phosphate and muriate of potash. The nutrients N and K were given in three splits *viz*., 50% as basal, 25% at 20 DAS, 25% at 45 DAS. Gypsum @ 400 kg ha^{-1} was applied on 40 DAS to get improved pegging and pod filling. TNAU Co 7 (Gn) was used as test variety. The spacing followed was 30 cm × 10 cm. Periodical irrigations were given at intervals of 8 to 10 days depending on climatic conditions. All other recommended package of practices was adopted as per the schedule. Observations on weed density was recorded with the help of 0.25 × 0.25 m (4 times-1m^2) quadrate and weed dry weight was assessed by oven drying weeds at 70 ºC for 72 hours The data was statistically analyzed by following the method of Gomez and Gomez (1984)[5]. The data pertaining to weeds were transformed by square root method and analyzed as suggested by Snedecor and Cochran (1967) [13]. Phytoxicity on crops was observed as suggested by Rao (1986) [11].

Result and Discussion

Weed parameters

Weed flora

The experimental field was infested with diverse weed species of grasses, sedges and broad leaved weeds. Among grasses, *Dactyloptenium aegyptium, Echinochloa colonum, Cynadon dactylon, Setaria verticiliate* were found and in sedges *Cyperus rotundus* and among broad leaved weeds *Trianthema portulacastrum, Digera arvensis, Amaranthus viridis, Boerhaavia diffusa, Corchorus olitorius, Portulaca olearacea, Sesbania aculeate, Desmanthus virgatus,* and *Parthenium hysterophorus* were found. The similar weed vegetation was observed by Manickam *et al.* (2000) [13] and Kalaichelvi *et al.* (2015) [7].

Dry weight of total weeds

Weed dry weight is the most important parameter to assess the weed competitiveness for the crop growth and productivity. It is evidenced from the Table 1, minimum dry weight was observed in treatments T_1 (Sulfentrazone 0.30 kg ha^{-1} e^+ at 1 DBS), T_5 (Sulfentrazone 0.40 kg ha^{-1} e^+ at 1 DBS), T_7 (Sulfentrazone 0.40 kg ha^{-1} e^+ at 2 DAS) and T_{13} (Sulfentrazone 0.40 kg ha^{-1} e^- at 1 DBS) followed by T_3 (Sulfentrazone 0.30 kg ha^{-1} e^+ at 2 DAS) and T_8 (Sulfentrazone 0.40 kg ha^{-1} e^+ at 3 DAS) in 15, 30 DAS and 45 DAS. Since the encapsulated herbicide released the active ingredient slowly which was helpful in killing the germinating weed seeds and to give reduced weed population and weed dry weight (Kabita Mishra, 2020) [6]. High dry weight of 6.76, 54.50 and 62.38 g m^{-2} was recorded in absolute control (T_{17}) at 15, 30 and 45 DAS respectively.

Weed Control Index

Weed Control Index is the measure of effectiveness of weed control treatments calculated based on weed dry weight. Higher weed control index was observed in T_7 (Sulfentrazone 0.40 kg ha^{-1} e^+ at 2 DAS), T_5 (Sulfentrazone 0.40 kg ha^{-1} e^+ at 1 DBS), T_{13} (Sulfentrazone 0.40 kg ha^{-1} e^- at 1 DBS) and T_1 (Sulfentrazone 0.30 kg ha^{-1} e^+ at 1 DBS) at 15 DAS, T_5 (Sulfentrazone 0.40 kg ha^{-1} e^+ at 1 DBS), T_7 (Sulfentrazone 0.40 kg ha^{-1} e^+ at 2 DAS) and T_1 (Sulfentrazone 0.30 kg ha^{-1} e^+ at 1 DBS) at both 30 and 45 DAS. Lower weed control index was observed in T_{17} (Absolute control) at 15,30 and 45 DAS followed by T_2 (Sulfentrazone 0.30 kg ha^{-1} e^+ at 1 DAS) and T_{10} (Sulfentrazone 0.30 kg ha^{-1} e^- at 1 DAS) at 15 and 30 DAS and T_2 (Sulfentrazone 0.30 kg ha^{-1} e^+ at 1 DAS), T_{10} (Sulfentrazone 0.30 kg ha^{-1} e^- at 1 DAS) and T_{14}(Sulfentrazone 0.40 kg ha^{-1} e^- at 1 DAS) at 45 DAS (Table 1)

Crop parameters
Phytotoxicity effect on groundnut

Phytotoxicity symptoms like stunting, discoloration were noted in crop stand and growth through visual observations. The herbicidal toxicity noted at 10, 15 and 30 DAHA (days after herbicide application) and rated in the scale 0- 10 which was suggested by Rao (1986) [11]. Both the doses of sulfentrazone herbicide (0.30 kg ha^{-1} and 0.40 kg ha^{-1}) showed visual toxic symptoms on groundnut crop and sulfentrazone applied at the rate of 0.30 kg ha^{-1} recovered faster with the comparison of 0.40 kg ha^{-1}. Sulfentrazone applied at the rate of 0.30 kg ha^{-1} recovered from symptoms at 25-30 DAHA at 1 DBS, 2 and 3 DAS (Table 2). Sulfentrazone applied at the rate of 0.40 kg ha^{-1} recovered from visual symptoms only after 35 DAHA.

Table 1: Effect of dose and time of application of encapsulated and non-encapsulated sulfentrazone herbicides formulations on total weed dry weight (g/m^2) and weed control index (%) in irrigated groundnut

T. No.	Treatment	Total weed dry weight(g/m^2)			Weed Control Index (%)		
		15 DAS	30 DAS	45 DAS	15 DAS	30 DAS	45 DAS
T1	Sulfentrazone 0.30 kg ha^{-1} e^+ at 1 DBS	1.06 (0.68)	0.87 (9.60)	3.82 (14.08)	89.94	82.39	77.43
T2	Sulfentrazone 0.30 kg ha^{-1} e^+ at 1 DAS	2.20 (4.52)	3.36 (28.63)	5.75 (33.52)	33.10	47.48	46.25
T3	Sulfentrazone 0.30 kg ha^{-1} e^+ at 2 DAS	1.35 (1.31)	1.33 (13.64)	4.55 (20.24)	80.56	74.98	67.54
T4	Sulfentrazone 0.30 kg ha^{-1} e^+ at 3 DAS	1.51 (1.79)	1.65 (13.11)	4.04 (15.86)	73.50	75.95	74.57
T5	Sulfentrazone 0.40 kg ha^{-1} e^+ at 1 DBS	0.95 (0.47)	0.71 (5.98)	3.29 (10.44)	93.00	89.03	83.26
T6	Sulfentrazone 0.40 kg ha^{-1} e^+ at 1 DAS	1.79 (2.71)	2.25 (20.49)	4.93 (23.81)	59.84	62.41	61.83
T7	Sulfentrazone 0.40 kg ha^{-1} e^+ at 2 DAS	0.93 (0.38)	0.65 (9.30)	3.58 (12.36)	94.44	82.93	80.19
T8	Sulfentrazone 0.40 kg ha^{-1} e^+ at 3 DAS	1.46 (1.65)	1.56 (12.16)	4.21 (17.24)	75.52	77.68	72.36
T9	Sulfentrazone 0.30 kg ha^{-1} e^- at 1 DBS	1.49 (1.78)	1.64 (13.37)	4.35 (18.42)	73.63	75.47	70.46
T10	Sulfentrazone 0.30 kg ha^{-1} e^- at 1 DAS	2.48 (5.71)	4.10 (26.59)	6.25 (38.58)	15.45	51.21	38.14
T11	Sulfentrazone 0.30 kg ha^{-1} e^- at 2 DAS	1.62 (2.14)	1.88 (16.43)	4.71 (21.70)	68.40	69.85	65.20
T12	Sulfentrazone 0.30 kg ha^{-1} e^- at 3 DAS	2.03 (3.64)	2.84 (16.93)	4.41 (19.05)	46.12	68.94	69.46
T13	Sulfentrazone 0.40 kg ha^{-1} e^- at 1 DBS	1.02 (0.55)	0.78 (12.28)	3.93 (15.05)	91.82	77.46	75.87
T14	Sulfentrazone 0.40 kg ha^{-1} e^- at 1 DAS	2.00 (3.53)	2.77 (30.20)	6.12 (37.03)	47.70	44.58	40.63
T15	Sulfentrazone 0.40 kg ha^{-1} e^- at 2 DAS	1.51 (1.78)	1.64 (14.27)	4.13 (16.59)	73.72	73.82	73.40
T16	Sulfentrazone 0.40 kg ha^{-1} e^- at 3 DAS	1.59 (2.14)	1.87 (18.64)	4.93 (24.01)	68.34	65.79	61.50
T17	Absolute control	2.69 (6.76)	4.73 (54.50)	7.93 (62.38)	0.00	0.00	0.00
	SEd	0.16	0.30	0.29	-	-	-
	CD(P= 0.05)	0.33	0.61	0.61	-	-	-

Table 2: Phytotoxicity rating

T. No	Treatments	Phytotoxicity rating		
		10 DAHA	15 DAHA	30 DAHA
T1	Sulfentrazone 0.30 kg ha^{-1} e^+ at 1 DBS	1	1	0
T2	Sulfentrazone 0.30 kg ha^{-1} e^+ at 1 DAS	2	1	1
T3	Sulfentrazone 0.30 kg ha^{-1} e^+ at 2 DAS	2	1	0
T4	Sulfentrazone 0.30 kg ha^{-1} e^+ at 3 DAS	1	1	0
T5	Sulfentrazone 0.40 kg ha^{-1} e^+ at 1 DBS	2	1	1
T6	Sulfentrazone 0.40 kg ha^{-1} e^+ at 1 DAS	3	2	1
T7	Sulfentrazone 0.40 kg ha^{-1} e^+ at 2 DAS	3	2	1
T8	Sulfentrazone 0.40 kg ha^{-1} e^+ at 3 DAS	3	2	1
T9	Sulfentrazone 0.30 kg ha^{-1} e^- at 1 DBS	1	1	0
T10	Sulfentrazone 0.30 kg ha^{-1} e^- at 1 DAS	2	1	0
T11	Sulfentrazone 0.30 kg ha^{-1} e^- at 2 DAS	2	1	0
T12	Sulfentrazone 0.30 kg ha^{-1} e^- at 3 DAS	1	1	0
T13	Sulfentrazone 0.40 kg ha^{-1} e^- at 1 DBS	3	2	1
T14	Sulfentrazone 0.40 kg ha^{-1} e^- at 1 DAS	3	2	1
T15	Sulfentrazone 0.40 kg ha^{-1} e^- at 2 DAS	3	2	1
T16	Sulfentrazone 0.40 kg ha^{-1} e^- at 3 DAS	3	2	1
T17	Absolute control	-	-	-

Yield attributes and yield
Pod yield

Application of different levels and time of application sulfentrazone herbicides with or without encapsulation significantly influenced the pod yield of groundnut. From the Table 3., it could be observed that higher dry pod yield of 149 g m^{-2} and 151 g m^{-2} were recorded in T_1 (Sulfentrazone 0.30 kg ha^{-1} e^+ at 1 DBS) and T_5 (Sulfentrazone 0.40 kg ha^{-1} e^+ at 1 DBS) respectively which were on par with T_3 (Sulfentrazone 0.30 kg ha^{-1} e^+ at 2 DAS). Similar results were noticed by Krausz *et al.*,(1998)[8] in soybean when sulfentrazone was applied @ 0.42 kg ha^{-1}. Lower yield was recorded in T_{17} (Absolute control) which was due to crop weed competition for resources throughout the growing period. The similar results of yield reduction in groundnut due to weeds were reported by Shalu Kumari *et al.*, (2020) [12] and Kumar *et al.*, (2013) [9].

Table 3: Effect of weed management practices on yield of groundnut

T. No	Treatments	Pod yield (g/m^2)	Haulm yield (g/ m^2)	Harvest index
T1	Sulfentrazone 0.30 kg ha^{-1} e$^+$ at 1 DBS	149	334	0.31
T2	Sulfentrazone 0.30 kg ha^{-1} e$^+$ at 1 DAS	96	255	0.27
T3	Sulfentrazone 0.30 kg ha^{-1} e$^+$ at 2 DAS	139	324	0.30
T4	Sulfentrazone 0.30 kg ha^{-1} e$^+$ at 3 DAS	128	313	0.29
T5	Sulfentrazone 0.40 kg ha^{-1} e$^+$ at 1 DBS	151	336	0.31
T6	Sulfentrazone 0.40 kg ha^{-1} e$^+$ at 1 DAS	85	246	0.26
T7	Sulfentrazone 0.40 kg ha^{-1} e$^+$ at 2 DAS	121	306	0.28
T8	Sulfentrazone 0.40 kg ha^{-1} e$^+$ at 3 DAS	124	309	0.29
T9	Sulfentrazone 0.30 kg ha^{-1} e$^-$ at 1 DBS	134	319	0.30
T10	Sulfentrazone 0.30 kg ha^{-1} e$^-$ at 1 DAS	80	241	0.25
T11	Sulfentrazone 0.30 kg ha^{-1} e$^-$ at 2 DAS	119	304	0.28
T12	Sulfentrazone 0.30 kg ha^{-1} e$^-$ at 3 DAS	114	299	0.28
T13	Sulfentrazone 0.40 kg ha^{-1} e$^-$ at 1 DBS	129	314	0.29
T14	Sulfentrazone 0.40 kg ha^{-1} e$^-$ at 1 DAS	79	240	0.25
T15	Sulfentrazone 0.40 kg ha^{-1} e$^-$ at 2 DAS	91	249	0.27
T16	Sulfentrazone 0.40 kg ha^{-1} e$^-$ at 3 DAS	108	293	0.27
T17	Absolute control	50	211	0.19
	SEd	7.59	15.43	0.017
	CD (P= 0.05)	15.47	31.43	0.035

Haulm yield

Among the treatments, it was observed that higher haulm yield was noticed in treatments T_1 (Sulfentrazone 0.30 kg ha^{-1} e$^+$ at 1 DBS) and T_5(Sulfentrazone 0.40 kg ha^{-1} e$^+$ at 1 DBS) which were on par with T_3 (Sulfentrazone 0.30 kg ha^{-1} e$^+$ at 2 DAS), T_4 (Sulfentrazone 0.30 kg ha^{-1} e$^+$ at 3 DAS), T_7 (Sulfentrazone 0.40 kg ha^{-1} e$^+$ at 2 DAS) and T_8 (Sulfentrazone 0.40 kg ha^{-1} e$^+$ at 3 DAS) (Table 3). The lower dry haulm yield was recorded in T_{17} (Absolute control) which was on par with T_{10} (Sulfentrazone 0.30 kg ha^{-1} e$^-$ at 1 DAS) and T_{14} (Sulfentrazone 0.40 kg ha^{-1} e$^-$ at 1 DAS). The yield results revealed that sulfentrazone applied on 1 DAS gave less dry pod and haulm yield.

Harvest Index

Harvest index is defined as the percentage of economic yield to biological yield and a useful measure of yield efficiency. The higher harvest index (HI) of 0.31 was observed in T_1 (Sulfentrazone 0.30 kg ha^{-1} e$^+$ at 1 DBS) and T_5 (Sulfentrazone 0.40 kg ha^{-1} e$^+$ at 1 DBS). The lowest harvest index of 0.19 was noticed in T_{17} (Absolute control) (Table 3).

Conclusion

From the present study, it can be concluded that sulfentrazone herbicide performs well in weed management for groundnut crop. Among the selected two doses (0.30 and 0.40 kg ha^{-1}), 0.30 kg ha^{-1} recorded less phytotoxicity on crops. Combining the advanced technology of nanoencapsulation with commercial formulation could reduce the weed population and lessen the dry weight of weeds for longer crop period owing to slow releasing ability of the herbicides. Thus, application of encapsulated sulfentrazone @ 0.30 kg ha^{-1} at one day before sowing gives more yield with better weed control followed by 2 DAS and 3 DAS.

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