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RESEARCH ARTICLE

Weed dynamics and growth of soybean in response to different sowing dates and weed management treatments under rainfed conditions of Nagaland

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ABSTRACT

An experiment was conducted at the School of Agricultural Sciences, Medziphema Campus, Nagaland University, Nagaland, India, during the *Kharif* seasons of 2021 and 2022. The objective was to examine the weed dynamics and the growth of soybean (*Glycine max* (L.) Merill) in response to different sowing dates and weed management treatments. A split-plot design was employed, with three sowing dates in the main plots and seven integrated weed management treatments in the sub-plots. The pooled results over the two years indicated that soybean sown on June 15 exhibited significantly lower total weed density and biomass and higher weed control efficiency. The June 15 sowing date also resulted in maximum soybean plant height, branches per plant, dry matter production, leaf area index, number of nodules, dry weight of nodules, seed yield and stover yield. Among the herbicide treatments, the sequential treatment of pre-emergence application (PE) pendimethalin 1000 g/ha followed by (*fb*) post-emergence application (PoE) of imazethapyr 100 g/ha at 20 days after sowing (DAS) recorded lower weed density, weed biomass, higher weed control efficiency with enhanced growth attributes and yield of soybean. It was concluded that early sowing (on June 15) and application of pendimethalin 1000 g/ha PE *fb* imazethapyr 100 g/ha PoE at 20 DAS, resulted in significant control of weeds and increased growth and yield of soybean.

Keywords: Soybean, Soil Solarization, Mulching, Pendimethalin, Imazethapyr, Weed management

INTRODUCTION

Soybean [*Glycine max* (L.) Merill] is a significant crop grown worldwide. It is used for food like tofu, soy milk, animal feed, products like biofuel and soy oil. Soybeans have the highest protein content among oilseeds, with 40-45% protein and 20-23% oil. They also have nutrients like calcium, phosphorus, iron, and vitamins. Soybeans provide complete protein with eight essential amino acids (Berad *et al*. 2016) and enriches soil through nitrogen fixation (Devi *et al*. 2011). India is the fifth largest producer after Brazil, USA, Argentina, China. In India soybean is mainly grown in Madhya Pradesh, Maharashtra, Rajasthan, and Karnataka (SOPA 2023). Despite production challenges, soybean remains vital to India agricultural sector due to health awareness and export opportunities.

Soybean productivity is significantly affected by management strategies, environmental conditions, and cultivar genetics (Nleya *et al*. 2020). The timing of sowing is crucial as it determines the environmental conditions such as temperature, photoperiod, and moisture that the crop will encounter during critical growth stages. Early sowing facilitates optimal utilization of the growing season and solar radiation, often resulting in extended vegetative periods and increased yields (Guo *et al*. 2022). Empirical studies indicated that early sowing enhances plant height, pod numbers, growth rates, and seed yield (Kaleri *et al*. 2023). The earlier sowing of soybeans enhanced growth and increased seed yield by 59.95% compared to later sowing dates (Jagtap *et al*. 2019). Furthermore, the sowing date significantly influences weed population, nutrient uptake, and overall productivity.

Among the constraints affecting soybean productivity in India, weed infestation is particularly severe. Soybean crop is subjected to continuous infestation of grassy, broad-leaved, and sedge weeds, resulting in growth and yield reductions ranging from 58% to 85%, with the extent of impact contingent upon the type and intensity of the weed presence (Padre *et al*. 2022). Additionally, weed pressure contributes to reduced nodulation and nitrogen fixation and elevates the risk of diseases and pests

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(Norsworthy *et al*. 2012). The critical period for crop and weed competition in soybean cultivation extends for 30 to 40 days post-sowing. Previous studies have demonstrated that superior weed control efficiency, along with enhanced soybean growth attributes and seed yield, can be achieved through hand hoeing twice (Rupareliya *et al*. 2020). However, hand weeding is laborious and is becoming costly due to increased labour shortage and labour wages. Thus, herbicide application offers significant advantages, including high efficiency in weed control, high selectivity, and cost-effectiveness compared to alternative weed management strategies (El-Metwally *et al.* 2017, Verma and Kushwaha 2019). Thus, the present study was conducted to identify suitable weed control measures in soybean sown under different sowing dates under rainfed conditions of Nagaland.

MATERIALS AND METHODS

Two-year field experiments were conducted during the *Kharif* seasons of 2021 and 2022 at the Agronomy Research Farm, School of Agricultural Sciences, Nagaland University, Medziphema Campus. The soil of the experimental site is sandy loam soil, acidic in reaction (pH 4.74), with medium organic carbon content (1.50%), available nitrogen (416.24 kg/ha), available phosphorus (18.60 kg/ha), and high available potassium (218.70 kg/ha). A split-plot design with three replications was used. Sowing dates were assigned to the main plots, *viz.* June 15, June 30, and July 15. Weed control treatments were allocated to sub-plots, *viz.* soil solarization with black polythene 25 days before sowing followed by (*fb*) hand weeding at 30 days after sowing (DAS), mulching with paddy straw at 5 t/ha *fb* hand weeding at 30 DAS, pre-emergence application (PE) of pendimethalin 1000 g/ha *fb* post-emergence application (PoE) of imazethapyr 100 g/ha at 20 DAS, pendimethalin 1000 g/ha *fb* intercultural operations at 30 DAS, imazethapyr 100 g/ha at 20 DAS *fb* intercultural operations at 30 DAS, hand weeding twice at 20 and 40 DAS, and weedy check, control. The plot size was 4 m × 3 m (12 m²) with plant spacing of 30 cm between rows and 10 cm between plants, using a seed rate of 70 kg/ha. Prior to final land preparation, well-decomposed farmyard manure (FYM) was uniformly applied at 10 t/ha and thoroughly incorporated into the soil. Soybean seeds (JS 97-52) were soaked overnight and inoculated with *Bradyrhizobium japonicum* strain before sowing. Seeds were manually sown at a depth of 5 cm. The recommended doses of N, P, and K at 20, 60, and 50 kg/ha, respectively, were applied as a basal dose during final land preparation. Herbicides were applied according to the treatments using a knapsack sprayer at a spray volume of 500 L/ha for both pre- and post-emergence applications. Plant protection measures were implemented to prevent pest attacks. Variables observed included weed species, weed density, weed dry weight (weed biomass), and weed control percentage, were assessed in each plot using a 1 m² quadrat. Data were transformed using the formula “x + 0.5, where x represents the actual weed density and biomass. Standard methods were employed to evaluate plant growth and yields. A combined analysis of variance (one-way ANOVA) over two years was conducted to determine treatment effects. The standard error of means (SEm+) and least significant difference [LSD (p=0.05)] were calculated for each parameter. All data analyses adhered to the principles of split-plot design as described by Gomez and Gomez (1984).

RESULT AND DISCUSSION

Weed flora

The predominant weed species associated with soybean during both years included *Digitaria sanguinalis*, *Eleusine indica*, and *Cynodon dactylon* among the grasses. The identified sedge species were *Cyperus iria* and *Cyperus rotundus*, while the broad-leaved weeds comprised of *Borreria latifolia*, *Ageratum conyzoides*, *Mollugo pentaphylla*, *Alternanthera sessilis*, *Mimosa pudica*, *Amaranthus viridis*, *Cleome rutidosperma*, *Scoparia dulcis*, and *Commelina benghalensis*. Among these, *Digitaria sanguinalis* and *Eleusine indica* predominant and posed greater competitiveness with the soybean (Walling *et al.* 2012, Apon and Nongmaithem 2022).

Effect on weed density and biomass

Variation in weed density was found to be significant with different soybean sowing dates (**Table 1**). At 40- and 60-days post-planting, soybeans sown on June 15 exhibited a reduced weed density compared to those planted at June 30 by 16, 11% and July 15 by 38, 29%, respectively which may be attributed to the early planting’s utilization of monsoonal moisture. Early planting facilitated enhanced soybean growth and competitive ability against weeds resulting in lower weed density and lesser availability and usage by weeds of moisture, nutrients, light, and space (Sahu *et al.* 2019).

The application of herbicides, whether pre-emergence or post-emergence, significantly reduced the overall weed occurrence across all species during crop growth compared to the untreated control

(**Table 1**). Throughout all growth stages, the highest total weed density was recorded in the untreated control. The pendimethalin 1000 g/ha *fb* imazethapyr 100 g/ha at 20 DAS, resulted in a substantial reduction in density of grassy, sedge, and broad-leaved weeds at 40 DAS due to the efficacy of both pre- and post-emergence herbicides application. Specifically, pendimethalin, has been identified as the most effective in controlling weeds by inhibiting seed germination and seedling development, particularly during the early stages of crop growth (Zain *et al*. 2020, Hasanuddin *et al*. 2022) and imazethapyr inhibited acetolactate synthase (ALS), a crucial enzyme, thereby impeding weed growth by disrupting cell division, nutrient translocation, hormonal balance, and DNA and cell growth, leading to rapid weed mortality (Emmiganur and Hosmath 2020, Roy *et al*. 2023). Hand weeding twice at 20 and 40 DAS effectively reduced both inter- and intra-row weeds.

The weed biomass increased over time. Among the various sowing dates, soybeans planted on June 15th resulted in a reduction in total weed biomass by 17, 11% and 45, 31% compared to those sown on June 30th and July 15th, respectively. This reduction in weed biomass can be attributed to the lower density of grasses, sedges, and broad-leaved weeds, which led to decreased utilization limited resources, thereby resulting in a lower weeds biomass (Sai *et al*. 2019, Hamoda *et al*. 2021).

The weed biomass increased with higher weed density, as well as with the variation in weed species and their growth. The application of herbicides resulted in a reduction in total weed biomass, as evidenced by their higher weed control efficiency. The highest weed biomass was observed under the weedy check at 40 and 60 DAS (**Table 2**). The pendimethalin 1000 g/ha PE *fb* imazethapyr 100 g/ha PoE at 20 DAS resulted in the lowest total weed biomass at 40 DAS. Similarly, at 60 DAS, hand weeding twice at 20 and 40 DAS, recorded the lowest total weed biomass among the herbicidal treatments confirming the findings of Kutariye *et al.* 2021 and Meena *et al.* 2022.

Table 1. Effect of sowing dates and integrated weed management treatments on weed density (no./m^{-2}) at 40,60 DAS (pooled data of 2021-2022)

Treatment	Weed density (no./m^2)							
	Grasses		Sedges		Broad-leaved		Total	
	40 DAS	60 DAS	40 DAS	60 DAS	40 DAS	60 DAS	40 DAS	60 DAS
Sowing dates (P)								
15th June	4.40 (21.6)	5.64 (34.2)	1.79 (3.1)	2.17 (5.1)	4.58 (23.1)	5.72 (35.2)	6.52 (47.9)	8.27 (74.59)
30th June	5.23 (29.6)	6.35 (42.6)	2.08 (4.2)	2.29 (5.7)	5.18 (29.0)	6.29 (41.9)	7.59 (62.9)	9.19 (90.38)
15th July	6.27 (41.2)	7.48 (58.1)	2.52 (6.2)	2.88 (8.7)	6.02 (38.4)	7.18 (53.6)	9.00 (85.9)	10.72 (120.5)
LSD (p=0.05)	0.25	0.18	0.10	0.06	0.09	0.10	0.20	0.09
Weed Management (W)								
Soil solarization 25 DBS *fb* hand weeding at 30 DAS	5.01 (25.4)	6.55 (43.3)	1.95 (3.4)	2.59 (6.3)	5.00 (24.9)	6.85 (46.8)	7.28 (53.8)	9.78 (96.49)
Mulching with paddy straw 5 t/ha *fb* hand weeding at 30 DAS	5.20 (27.2)	6.77 (46.0)	1.98 (3.5)	2.62 (6.5)	5.32 (28.2)	7.32 (53.5)	7.63 (59.0)	10.26 (106.0)
Pendimethalin 1000 g/ha PE *fb* imazethapyr 100 g/ha PoE at 20 DAS	3.82 (14.8)	5.22 (27.3)	1.55 (2.0)	2.09 (4.0)	3.42 (11.6)	4.91 (24.0)	5.27 (28.5)	7.40 (55.4)
Pendimethalin 1000 g/ha *fb* intercultural at 30 DAS	4.44 (20.10)	6.12 (37.7)	1.88 (3.1)	2.34 (5.0)	4.51 (20.2)	6.05 (36.6)	6.53 (43.4)	8.87 (79.4)
Imazethapyr 100 g/ha 20 DAS *fb* Intercultural at 30 DAS	4.10 (17.0)	5.86 (34.6)	1.62 (2.2)	2.17 (4.3)	3.84 (14.6)	5.46 (29.8)	5.76 (33.9)	8.25 (68.8)
Hand weeding twice at 20 and 40 DAS	5.81 (33.8)	4.73 (22.3)	2.43 (5.4)	0.90 (0.4)	6.07 (36.8)	4.44 (19.6)	8.69 (76.1)	6.48 (42.4)
Weedy check (control).	8.74 (77.0)	10.16 (103.5)	3.51 (11.9)	4.4 (19.0)	8.67 (75.1)	9.74 (94.7)	12.77 (164)	14.72 (217.4)
LSD (p=0.05)	0.29	0.25	0.11	0.17	0.14	0.20	0.23	0.27

Original values were subjected to square root transformation. Figures in parentheses are the original values. DAS = date of sowing; DBS = days before seeding, fb = followed by; PE = pre-emergence application; PoE = post emergence application

Weed control efficiency (WCE)

Weed control efficiency denotes the relative efficiency of weed control practices compared to weedy check. The higher WCE of 71.42 and 61.65 % at 40 and 60 DAS respectively, were observed when the crop was sown on June 15th. In contrast, the lowest efficiencies were noted with the late sowing date. Samant and Mohanty (2017) also reported the improved weed control efficiency with earlier sowing dates.

The maximum WCE of 87 and 76 % at 40 and 60 DAS respectively, was recorded with pendimethalin 1000 g/ha PE *fb* imazethapyr 100 g/ha PoE at 20 DAS, among herbicides treatments, which can be attributed to the minimal weed density, biomass and increased seed yield, respectively, achieved through effective suppression of weed growth (Raj *et al.* 2020, Pawar *et al.* 2022).

Effect on soybean growth and yield

The timing of sowing had a significant influence on the growth of soybeans across all developmental stages (**Table 3**). Due to their photosensitivity, soybeans sown early, on June 15th, exhibited the highest pooled values for plant height, branches/plant, dry weight/plant, leaf area, root nodules/plant, dry weight of root nodules, seed yield and stover yield in compared to other sowing dates. This may be attributed to early sowing providing soybean plants with favourable climatic conditions and temperatures, as well as a comparatively extended growth period, thereby enabling the plants to optimize their growth and development potential, ultimately resulting in higher yield (Dandge *et al.* 2020). Furthermore, the observed reduction in growth attributes and yield with delayed planting may be due to rapid changes in photoperiod, which expedite the transition to reproductive stages, consequently reducing the time available for vegetative growth (Kumagai and Takahashi 2020).

The pooled mean values over the two years indicate that pendimethalin 1000 g/ha PE *fb* imazethapyr 100 g/ha PoE at 20 DAS resulted in significantly enhanced soybean growth parameters (**Table 3**) and the lowest values for these growth attributes and yield were observed in the weedy check plots. The substantial enhancement in growth attributes and yield can be ascribed to the effective management of weeds during critical stages of crop development. This management facilitated improved

Table 2. Effect of sowing dates and integrated weed management treatments on weed biomass (g/m²) at 40,60 DAS (pooled data of 2021-2022)

Treatment	Weed biomass (g/m²)							
	Grasses		Sedges		Broad-leaved		Total	
	40 DAS	60 DAS	40 DAS	60 DAS	40 DAS	60 DAS	40 DAS	60 DAS
Sowing dates (P)								
15th June	2.65 (8.17)	4.27 (19.28)	1.18 (0.98)	1.45 (1.96)	1.71 (2.83)	3.02 (9.63)	3.20 (11.98)	5.34 (30.87)
30th June	3.09 (10.74)	4.74 (23.53)	1.30 (1.27)	1.46 (2.00)	1.96 (3.73)	3.42 (12.11)	3.75 (15.74)	5.95 (37.65)
15th July	3.84 (15.48)	5.56 (31.90)	1.56 (2.05)	1.67 (2.64)	2.34 (5.47)	3.97 (16.32)	4.65 (23.00)	6.97 (50.87)
LSD (p=0.05)	0.15	0.18	0.08	0.07	0.07	0.09	0.13	0.12
Weed Management (W)								
Soil solarization 25 DBS *fb* hand weeding at 30 DAS	2.93 (8.48)	4.88 (23.71)	1.27 (1.15)	1.60 (2.10)	1.83 (2.94)	3.70 (13.40)	3.55 (12.57)	6.26 (39.22)
Mulching with paddy straw 5 t/ha *fb* hands weeding at 30 DAS	3.05 (9.13)	5.08 (25.65)	1.29 (1.19)	1.62 (2.16)	1.92 (3.27)	3.98 (15.53)	3.69 (13.59)	6.58 (43.34)
Pendimethalin 1000 g/ha PE *fb* imazethapyr 100 g/ha PoE at 20 DAS	2.16 (4.57)	3.88 (14.86)	1.07 (0.67)	1.19 (0.96)	1.37 (1.45)	2.66 (6.74)	2.59 (6.70)	4.75 (22.56)
Pendimethalin 1000 g/ha PE *fb* intercultural at 30 DAS	2.48 (6.06)	4.61 (21.18)	1.20 (.97)	1.39 (1.46)	1.70 (2.46)	3.22 (10.02)	3.08 (9.50)	5.71 (32.66)
Imazethapyr 100 g/ha PoE 20DAS *fb* Intercultural at 30 DAS	2.32 (5.28)	4.45 (19.75)	1.11 (0.76)	1.24 (1.10)	1.51 (1.85)	2.93 (8.29)	2.81 (7.89)	5.38 (29.14)
Hand weeding twice at 20 and 40 DAS	3.50 (12.02)	3.60 (12.71)	1.50 (1.78)	0.84 (0.23)	2.23 (4.57)	2.35 (5.19)	4.30 (18.36)	4.27 (18.14)
Weedy check (control).	5.9 (34.72)	7.51 (56.47)	1.98 (3.52)	2.80 (7.38)	3.45 (11.52)	5.45 (29.65)	7.05 (49.75)	9.65 (93.50)
LSD (p=0.05)	0.20	0.21	0.10	0.10	0.09	0.16	0.18	0.21

Original values were subjected to square root transformation. Figures in parentheses are the original values. DAS = date of sowing; DBS = days before seeding, *fb* = followed by; PE = pre-emergence application; PoE = post emergence application

Table 3. Effect of sowing dates and integrated weed management treatments on weed control efficiency (WCE), soybean plant growth parameter and yield (pooled data of 2021-2022)

Treatment	Weed control efficiency (%)		Plant height (cm)	Branches /plant	Dry matter (g/plant)	LAI	Root nodules/ plant	Dry wt. of nodules	Seed yield (t/ha)	Stover yield (t/ha)
	40 DAS	60 DAS	at harvest	at harvest	60 DAS	60 DAS	60 DAS	60 DAS		
Sowing dates (P)										
15th June	71.42	61.65	59.54	3.86	27.22	2.73	40.42	0.41	2.01	2.44
30th June	68.04	58.17	54.83	3.38	24.65	2.48	35.53	0.35	1.72	2.33
15th July	59.52	52.61	48.92	2.87	19.48	1.95	29.45	0.31	1.25	2.13
LSD (p=0.05)	-	-	1.94	0.15	1.08	0.13	1.49	0.015	0.09	0.12
Weed Management (W)										
Soil solarization 25 DBS *fb* hand weeding at 30 DAS	75.11	58.01	54.16	3.30	22.62	2.31	31.68	0.33	1.53	2.18
Mulching with paddy straw 5 t/ha *fb* hands weeding at 30 DAS	73.02	53.46	52.96	3.22	21.82	2.16	28.16	0.30	1.38	2.02
Pendimethalin 1000 g/ha PE *fb* imazethapyr 100 g/ha PoE at 20 DAS	86.99	76.00	59.48	3.77	25.73	2.65	42.21	0.42	2.05	2.66
Pendimethalin 1000 g/ha PE *fb* intercultural at 30 DAS	81.48	65.03	56.27	3.48	23.38	2.42	35.32	0.35	1.74	2.40
Imazethapyr PoE 100 g/ha 20 DAS *fb* Intercultural at 30 DAS	84.58	69.08	56.99	3.58	24.14	2.52	37.99	0.38	1.91	2.59
Hand weeding twice at 20 and 40 DAS	63.12	80.75	61.21	3.95	28.64	2.72	48.07	0.45	2.21	2.78
Weedy check (control).	0.00	0.00	39.95	2.28	20.16	1.90	22.52	0.26	0.81	1.49
LSD (p=0.05)	-	-	2.82	0.22	0.96	0.19	1.95	0.02	0.07	0.16

DBS= days before seeding; *fb* = followed by; PE = Pre-emergence application; PoE = Post emergence application

growth conditions, including adequate space, light, moisture, and nutrients, as well as enhanced accumulation of photosynthates, thereby promoting superior growth, development, and spatial distribution of the soybean crop (Samudre *et al*. 2019, Chouhan and Verma 2023, Jadon *et al*. 2019).

It is concluded that the early sowing of soybean (on June 15) and application of pendimethalin 1000 g/ha PE *fb* imazethapyr 100 g/ha PoE at 20 DAS, provides optimal weed control and enhances the soybean growth attributes and yield under the rainfed conditions in Nagaland.

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