Crossref

IJBSM October 2025, 16(10): 01-08

Article AR6470

Research Article

Natural Resource Management

DOI: HTTPS://DOI.ORG/10.23910/1.2025.6470

A Study on Nutrient Uptake by Crops and Weeds under Different Planting Dates and Integrated Weed Management Strategies in Soybean (*Glycine max* L.)

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ABSTRACT

The experiment was conducted during (June–October, 2021 and 2022) at School of Agricultural Sciences, Medziphema Campus, Nagaland University, India, to investigate the effects of sowing dates and weed management strategies on nutrient uptake by crops and weeds in soybean (*Glycine max* L.) cultivation. A split-plot design was employed with three sowing dates (June 15, June 30, and July 15) and seven weed control treatments, including soil solarization, mulching, herbicides, manual weeding, and a weedy check. The results showed that early sowing on June 15 significantly reduced weed density, dry weight, and nutrient depletion by weeds compared with that on later sowing dates. Among the weed control treatments, hand weeding at 20 and 40 days after sowing (DAS) was the most effective in controlling weeds. The application of pendimethalin 30 EC at 1 kg ha^{-1} as pre-emergence (PE)+imazethapyr 10 SL at 100 g ha^{-1} as post-emergence (PoE) at 20 DAS was the best herbicidal treatment, resulting in the lowest weed count, dry weight and nutrient depletion. Nutrient uptake by soybean seed and stover was highest with the June 15 sowing date and two hand weedings, followed by the application of pendimethalin (PE)+imazethapyr application (PoE). This study emphasizes the significance of early sowing and effective weed management in maximizing the nutrient uptake, growth, and yield of soybean under the prevailing conditions in Nagaland, India.

KEYWORDS: Soybean, sowing, weed, herbicides, nutrient uptake

***Citation* (VANCOUVER):** Zion and Longkumer, A Study on Nutrient Uptake by Crops and Weeds under Different Planting Dates and Integrated Weed Management Strategies in Soybean (*Glycine max* L.). *International Journal of Bio-resource and Stress Management,* 2025; 16(10), 01-08. HTTPS://DOI.ORG/10.23910/1.2025.6470.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

RECEIVED on 27th June 2025 RECEIVED in revised form on 28th September 2025 ACCEPTED in final form on 12th October 2025 PUBLISHED on 31st October 2025

1. INTRODUCTION

Soybeans (*Glycine max*) are a key agricultural crop globally due to their nutritional and economic value. Originally from China, soybeans have evolved into one of the most vital protein and oil sources worldwide. In 2019, the area dedicated to soybean cultivation spanned 137 million hectares across 95 countries. The United States leads soybean cultivation through advanced breeding practices (Anderson et al., 2019). India ranks fifth in production, and the major soybean production region are Madhya Pradesh, Maharashtra, Rajasthan, and Karnataka (Anonymous, 2023). Soybeans contribute to food security as they constitute 25% of the world's edible oil and contain substantial portion of livestock protein (Mishra et al., 2024). As a protein rich food source, soybeans are essential for human diets and animal feed. Moreover, enhance soil fertility through nitrogen fixation and play a substantial role in crop rotation systems (Kim et al., 2016). The crop has multiple industrial applications, including biodiesel production and its use in pharmaceuticals and cosmetics.

The timing of soybean planting significantly influences their growth and yield across various regions and climatic conditions (Borowska and Prusinski, 2021). The planting date affects the duration of vegetative and reproductive growth phases. In India, early soybean planting can enhance yield and mitigate environmental impact, which is crucial for sustainable agriculture. Early planting extends the growth period, resulting in taller plants, increased foliage, and higher yields due to favourable temperature and photoperiod conditions (Umburanas et al., 2019; Fordonski et al., 2023; Zeleke and Nendel, 2024). Planting on June II fortnight optimizes nitrogen, pohosphorus and potassium uptake, due to favorable soil conditions (Basavaraj et al., 2020). Sikka et al. (2018) also mentioned that planting of soybean on May 20 maximizes phosphorus and potassium uptake, while June 30 sowing date resulted in higher total nitrogen uptake, illustrating the impact of timing on nutrient absorption. Conversely, late planting diminishes growth and yield due to shorter growth periods and less favorable conditions (Battisti et al., 2018; Serafin-Andrzejewska et al., 2021). Optimal planting timing facilitates efficient utilization of soil and climatic conditions, thereby minimizing yield loss (Mandic et al., 2020). . The planting date also influences weed management; early planting enables rapid ground coverage, thereby reducing weed proliferation through shading (Murphy and Gossett, 1981). Early planting decreases weed density and biomass, which can adversely affect crop yield, underscoring the importance of timing in weed management (Byiringiro et al., 2018; Sai et al., 2019). Late planting may result in increased weed competition for resources (Zandoná et al., 2018).

Weed infestation poses a significant challenge to soybean growth and yield. The slow initial growth phase of soybeans renders them particularly susceptible to severe weed infestations. It is crucial to maintain a weed-free environment during the first 45 days after sowing; without effective control measures, soybean yield losses averaged 52.1% due to weed interference (Soltani et al., 2017). Weeds deplete the soil of 30–60 kg of nitrogen, 8–10 kg of phosphorus, and 40–100 kg of potash per hectare (Bali et al., 2017). Inadequate weed control diminishes fertilizer efficiency and overall productivity. Effective weed management is essential to minimize nutrient depletion and enhance fertilizer utilization. The application of herbicides reduces nutrient loss owing to weed growth, thereby improving crop nutrient uptake and yield. It also offers significant advantages, including high efficiency in weed control, high selectivity, and cost-effectiveness compared to alternative weed management strategies. In light of prior research, the present study was conducted to investigate the nutrient uptake by crops and weeds under different planting dates and integrated weed management strategies in soybean (*Glycine max* L.)

2. MATERIALS AND METHODS

The Field experiments were conducted over two consecutive years during (June–October, 2021 and 2022) kharif season at the Agronomy Research Farm, School of Agricultural Sciences, Nagaland University, Medziphema Campus. The objective of this study was to investigate the effects of sowing dates and weed management strategies on nutrient uptake by both crops and weeds in soybean (*Glycine max* L.) cultivation. The experimental site was characterized by sandy loam soil with an acidic pH of 4.74, medium organic carbon content (1.50%), available nitrogen (416.24 kg ha^{-1}), available phosphorus (18.60 kg ha^{-1}), and high available potassium (218.70 kg ha^{-1}). A split-plot design, with three replications was employed. The main plots were assigned different sowing dates: June 15, June 30, and July 15. Sub-plots received various weed control treatments: soil solarization with black polythene 25 days before sowing+hand weeding at 30 DAS, mulching with paddy straw at 5 t ha^{-1}+hand weeding at 30 DAS, pendimethalin 30 EC at 1 kg ha^{-1} as pre-emergence (PE)+imazethapyr 10 SL at 100 g ha 1 as post-emergence (PoE) at 20 DAS, pendimethalin 30 EC at 1 kg ha^{-1} (PE)+intercultural operations at 30 DAS, imazethapyr 10 SL at 100 g ha^{-1} (PoE) at 20 DAS+intercultural operations at 30 DAS, hand weeding at 20 and 40 DAS, and a weedy check control. Each plot measured 4×3 m^2 (12 m^2) with a plant spacing of 30 cm between rows and 10 cm between plants, using a seed rate of 70 kg ha^{-1}. Before the final land preparation, well-decomposed farmyard manure (FYM) was evenly applied at 10 t ha^{-1} and thoroughly incorporated into the soil. Soybean seeds (JS 97–52) were soaked overnight and inoculated with Bradyrhizobium japonicum before sowing. Seeds were manually planted at a depth of 5 cm. Recommended doses of N, P, and K at 20, 60, and 50 kg ha^{-1}, respectively, were applied as basal dose during the final land preparation. Herbicides were applied according to the treatments using a knapsack sprayer at a spray volume of 500 L ha^{-1}. Plant protection measures have been implemented to prevent pest attacks. The observed variables included weed species, number of weeds, and weed dry weight, assessed in each plot using a 0.5×0.5 m² quadrat and then converted to per square meter. Data were transformed using the formula √x+0.5, where x represents the actual weed count and the weed dry weight. Standard methods were used to evaluate plant growth, yields, and nutrient uptake by weeds and crops at harvest. A combined analysis of variance (one-way ANOVA) over two years was conducted to determine the treatment effects. The standard error of means (SEm±) and the least significant difference [LSD (p=0.05)] were calculated for each parameter. All data analyses adhered to the principles of split-plot design described by Gomez and Gomez (1984).

3. RESULTS AND DISCUSSION

3.1. *Weed flora*

Important weed flora associated with soybean crops during both experimental seasons included *Digitaria sanguinalis*, *Eleusine indica*, and *Cynodon dactylon* among the grasses. The sedge species identified were *Cyperus iria* and *Cyperus rotundus*, whereas the broad-leaved weeds were *Borreria latifolia*, *Ageratum conyzoides*, *Mollugo pentaphylla*, *Alternanthera sessilis*, *Mimosa pudica*, *Amaranthus viridis*, *Cleome rutidosperma*, *Scorparia dulcis*, and *Commelina benghalensis*. Similar observations have been documented in previous studies by Sepat et al. (2017); Apon and Nongmaithem (2022) regarding the presence of similar weed flora in experimental plots.

3.2. *Weed density and weed dry weight*

Significant variations in weed density and dry weight were observed at different sowing dates (Table 1). Soybeans sown on June 15 exhibited an 11% reduction in weed presence compared to those sown on June 30, and a 29% reduction

Table 1: Effect of sowing dates and integrated weed management practices on weed density (no. m^{-2}) and weed dry weight (g m^2) at 60 DAS

Treatments	Weed density (no. m^{-2}) 60 DAS		Weed dry weight (g m^2) 60 DAS	
	2021	2022	2021	2022
Sowing dates (P)				
15th June	8.56 (79.96)	7.98 (69.22)	5.55 (33.45)	5.12 (28.28)
30th June	9.39 (94.76)	8.98 (86.00)	6.13 (40.20)	5.77 (35.09)
15th July	11.09 (128.55)	10.36 (112.52)	7.23 (54.79)	6.72 (46.94)
SEm±	0.03	0.05	0.03	0.06
LSD (p=0.05)	0.11	0.19	0.13	0.25
Weed Management (W)				
Soil solarization (25 DBS)+hand weeding at 30 DAS	10.05 (101.68)	9.51 (91.30)	6.47 (41.82)	6.04 (36.61)
Mulching with paddy straw 5 t ha^{-1}+hands weeding at 30 DAS	10.55 (111.86)	9.98 (100.15)	6.76 (45.69)	6.40 (40.99)
Pendimethalin 30 EC@1 kg ha^{-1}+imazethapyr 10 SL@100 g ha^{-1} at 20 DAS	7.58 (58.16)	7.23(52.77)	4.86(23.56)	4.65 (21.56)
Pendimethalin 30 EC@1 kg ha^{-1}+intercultural at 30 DAS	9.09 (83.63)	8.64 (75.32)	5.85(34.39)	5.56 (30.94)
Imazethapyr 10 SL@100 g ha^{-1} (20 DAS)+ Intercultural at 30 DAS	8.56 (74.28)	7.93 (63.44)	5.60 (31.61)	5.17 (26.67)
Hand weeding at 20 and 40 DAS	6.72 (45.77)	6.24 (39.13)	4.45(19.68)	4.08 (16.59)
weedy check (control)	15.22 (232.23)	14.22 (202.62)	10.14 (102.95)	9.17 (84.06)
SEm±	0.15	0.11	0.12	0.09
LSD (p=0.05)	0.43	0.32	0.35	0.26

Figures in parentheses are the original values, and the data were subjected to a square root transformation √x+0.5

compared to those sown on July 15. Over time, the dry matter of the weeds increased. Early sowing of the crop also resulted in a reduction in total weed dry weight by 11% and 31% compared with those sown on June 30 and July 15, respectively. This phenomenon is likely attributable to early planting capitalizing on monsoonal moisture, thereby enhancing soybean growth and competitiveness against weeds. Consequently, weeds consume less moisture, nutrients, light, and space, leading to a reduced weed population and, subsequently, a lower weed dry weight (Samant and Mohanty, 2017; Sahu et al., 2019; Hamoda et al., 2021).

Utilizing herbicides, whether before or after weed emergence, markedly decreased the presence of weeds across all species during crop development compared with the control plots (Table 1). The most effective weed reduction was achieved through two rounds of hand weeding at 20 and 40 DAS. Hand weeding at these intervals successfully removed weeds both between and within rows. Among the herbicide treatments, pendimethalin 30 EC at 1 kg ha^{-1} (PE)+imazethapyr 10 SL at 100 g ha^{-1} (PoE) at 20 DAS recorded the lowest weed population and lowest dry weight of weeds compared to other herbicides applications. The reduction may be due to the fact that the herbicides inhibit a key enzyme, thereby hindering weed growth by disrupting cell division, nutrient movement, hormonal balance, DNA and cell growth, leading to rapid weed death (Vijay et al., 2018; Verma and Kushwaha, 2019; Meena et al., 2022; Roy et al., 2023).

3.3. Nutrient depleted by weeds

The data presented in Table 2 provides evidence of significant influences in the depletion of nitrogen, phosphorus, and potassium (N, P and K) by weeds across different sowing dates. Significantly the lowest nutrient depletion was recorded when the crop was sown on June 15, whereas higher nutrient depletion values were observed for delayed sowing. The increased depletion of N, P and K by weeds associated with the delayed sowing date may be attributed to the higher intensity of weeds and dry matter accumulation, facilitated by favourable environmental

Table 2: Effect of sowing dates and integrated weed management practices on N, P, and K uptake (kg ha^{-1}) by weed and soybean crop (pooled data of 2021–2022)

Treatments	Nutrient uptake by weeds (kg ha^{-1})			Nutrient uptake by crops (kg ha^{-1})					
				N		P		K	
	N	P	K	Seed	Stover	Seed	Stover	Seed	Stover
Sowing dates (P)									
15th June	11.09	1.15	4.67	120.49	51.98	5.73	5.23	29.77	55.04
30th June	14.15	1.59	5.73	102.32	47.92	4.84	4.88	25.19	50.99
15th July	20.13	2.17	7.70	73.36	42.74	3.41	4.28	17.78	45.18
SEm±	0.41	0.02	0.15	1.17	1.21	0.10	0.06	0.47	1.25
LSD (p=0.05)	1.32	0.08	0.49	3.80	3.97	0.34	0.20	1.52	4.09
Weed management (W)									
Soil solarization (25 DBS)+hand weeding at 30 DAS	12.32	1.55	5.63	87.87	43.58	4.16	3.87	21.61	46.31
Mulching with paddy straw 5 t ha^{-1}+hands weeding at 30 DAS	16.55	1.99	7.38	76.42	39.01	3.45	3.22	19.14	41.91
Pendimethalin 30 EC@1 kg ha^{-1}+imazethapyr 10 SL@100 g ha^{-1} at 20 DAS	5.10	0.56	1.34	126.59	60.11	6.34	6.53	30.86	60.76
Pendimethalin 30 EC@1 kg ha^{-1}+intercultural at 30 DAS	9.45	1.09	3.82	103.67	48.88	4.75	5.08	25.15	51.51
Imazethapyr 10 SL @ 100 g ha^{-1} (20 DAS)+Intercultural at 30 DAS	8.08	0.85	2.63	114.38	53.47	5.50	5.69	27.90	57.11
Hand weeding at 20 and 40 DAS	3.66	0.45	1.01	138.00	61.97	6.54	7.18	33.94	67.70
Weedy check (control)	50.69	4.98	20.43	44.15	25.82	1.88	1.99	11.12	27.54
SEm±	0.73	0.05	0.25	2.16	1.42	0.12	0.15	0.51	1.41
LSD (p=0.05)	2.06	0.13	0.71	6.09	3.93	0.34	0.43	1.44	3.99

conditions for weed growth (Neenu et al., 2017; Kumari, 2020; Sharma et al., 2021).

Nutrient depletion by weeds was also found to be significant because of the different weed management practices. The weedy check exhibited significantly higher depletion of N, P and K than the other treatments (Table 2). Among the various weed control treatments, the lowest uptake of N, P, and K was recorded in hand-weeding (20 and 40 DAS), which was statistically at par with the application of pendimethalin 30 EC at 1 kg ha^{-1} (PE)+imazethapyr 10 SL at 100 g ha^{-1} (PoE) at 20 DAS. This outcome could be attributed to the reduced dry matter accumulation of weeds, resulting from broad-spectrum weed control by herbicides at the initial stage, as well as the manual removal of weeds. These results were in close agreement with those reported by Dhakad et al. (2022), and Dhayal et al. (2022).

3.4. Nutrient uptake by seed and stover

The highest uptake of N, P, and K by seed and stover was observed when the crop was sown on June 15, whereas delayed sowing resulted in the lowest uptake of N, P and K. The increased nutrient uptake at the earlier sowing date may be attributed to more evenly distributed rainfall, which facilitated earlier crop establishment, more vigorous root growth, and extended growth periods. These factors collectively enhance the absorption of nutrients and moisture from the soil, thereby substantially improving seed development and nutrient uptake. These findings are consistent with those reported by Mahesh et al. (2017), Nawale et al., (2018) and Kaur et al. (2024).

Nitrogen, phosphorus, and potassium uptake by seeds and stover under various integrated weed management practices also exhibited significant differences, (Table 2). The lowest nutrient uptake by the seed and stover was recorded in the weedy check. Notably, the highest values of N, P, and K uptake were recorded with two hand weeding (20 and 40 DAS), followed by the application of pendimethalin 30 EC at 1 kg ha^{-1} as (PE)+imazethapyr 10 SL at 100 ha^{-1} (PoE) at 20 DAS in nutrient uptake by seed, whereas, nutrients uptake by stover was found to be at par to two hand weeding. The enhanced uptake of nutient in seeds and stover can be attributed to the effective control and suppression of weed growth, which provides a weed-free environment for an extended period, allowing for the optimal utilization of available and applied nutrients. This also facilitated better

Table 3: Effect of sowing dates and integrated weed management practices on growth, yield attributes and yield of soybean (pooled data of 2021–2022)

Treatments	Plant height at harvest	No. of branches at harvest	No. of pods $plant^{-1}$	Pod length (cm)	100 seed weight	Seed yield (t ha^{-1})	Stover yield (q ha^{-1})
Sowing dates (P)							
15th June	59.54	3.86	68.20	3.60	10.63	2.01	2.44
30th June	54.83	3.38	64.18	3.51	10.13	1.72	2.33
15th July	48.92	2.87	36.32	3.47	9.72	1.25	2.13
SEm±	0.59	0.05	0.92	0.03	0.10	0.27	0.36
LSD (*p*=0.05)	1.94	0.15	3.01	NS	0.32	0.89	1.17
Weed management (W)							
Soil solarization (25 DBS)+hand weeding at 30 DAS	54.16	3.30	51.57	3.52	9.90	1.53	2.18
Mulching with paddy straw 5 t ha^{-1}+hands weeding at 30 DAS	52.96	3.22	49.62	3.50	9.47	1.38	2.02
Pendimethalin 30 EC @ 1 kg ha^{-1}+imazethapyr 10 SL@100 g ha^{-1} at 20 DAS	59.48	3.77	66.42	3.55	10.92	2.05	2.66
Pendimethalin 30 EC @ 1 kg ha^{-1}+intercultural at 30 DAS	56.27	3.48	56.05	3.52	10.12	1.75	2.4
Imazethapyr 10 SL @ 100 g ha^{-1} (20 DAS)+Intercultural at 30 DAS	56.99	3.58	60.22	3.53	10.43	1.91	2.59
Hand weeding at 20 and 40 DAS	61.21	3.95	72.60	3.59	11.43	2.22	2.78
Weedy check (control)	39.95	2.28	37.16	3.47	8.83	8.14	14.87
SEm±	1.00	0.08	1.59	0.04	0.18	0.26	0.57
LSD (*p*=0.05)	2.82	0.22	4.47	NS	0.51	0.74	1.61

root growth and establishment, ultimately resulting in higher nutrient content in seeds and stover and consequently higher yield. These results are in close agreement with the findings of Raj et al. (2020), and Vishwakarma et al. (2023).

3.5. Crop growth and yield

The timing of planting is a critical determinant of the developmental trajectory of soybean across all growth stages. Soybeans sown early, specifically on June 15, exhibited the highest combined metrics for plant height (59.54 cm), branches plant^{-1} (3.86), number of pods plant^{-1} (68.20), test weight (10.63 g), seed yield (2.01 t ha^{-1}), and stover yield (2.44 t ha^{-1}) relative to other planting dates. This phenomenon can be attributed to the early planting of soybean plants with favourable climatic conditions and temperatures, coupled with an extended growth period, thereby enabling the plants to optimize their growth and developmental potential (Sumalatha and Uppar, 2019; El-Toum et al., 2020; Ksiezak and Bojarszczuk, 2022).

Two rounds of manual weeding resulted in significantly enhanced soybean growth and yield, as illustrated in Table 3. Among herbicide-based weed management strategies, the application of pendimethalin 30 EC at 1 kg ha^{-1} (PE)+imazethapyr 10 SL at 100 g ha^{-1} (PoE) at 20 DAS led to markedly improved soybean growth and yield. This treatment achieved a plant height of 59.48 cm, branches plant^{-1} (3.77), pods plant^{-1} (66.42), test weight (10.92 g), seed yield (20.53 q ha^{-1}), and stover yield (26.59 q ha^{-1}). Conversely, the lowest values for these growth and yield parameters were observed in weedy check plots. The significant enhancement in growth attributes can be ascribed to effective weed management during the critical crop development stages. This management provided improved growth conditions, such as adequate space, light, moisture, and nutrients, as well as increased accumulation of photosynthates, thereby augmenting the growth, development, and spatial distribution of the soybean crop (Jadon et al., 2019; Kalyan et al., 2024; Pawar et al. 2022, Chouhan and Verma, 2023). The diminished growth and yield observed in the weedy check plots were likely due to the unmitigated competition between the crop and weeds, which inhibited cell division or enlargement (Akter et al., 2016).

4. CONCLUSION

Early sowing on June 15 resulted in reduced weed density, dry weight, and nutrient depletion, while increasing nutrient uptake and improving crop growth and yield. Among weed management practices, two rounds of hand weeding and the application of pendimethalin 30 EC at 1 kg ha^{-1} (PE)+imazethapyr 10 SL at 100 g ha^{-1} (PoE) at 20 DAS were most effective in controlling weeds, reducing nutrient depletion, and enhancing nutrient uptake and crop growth and yield.

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