Plant Archives Vol. 26, Supplement 2, 2026 pp. 1955-1962 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.supplement-2.243

SUBSTITUTING A QUARTER OF THE MINERAL FERTILIZER WITH AN N P K Zn MICROBIAL CONSORTIUM AND POST-EMERGENCE HERBICIDE GOVERN GROWTH AND YIELD ATTRIBUTES OF COWPEA (*Vigna unguiculata* L. Walp.)

Rahul[1], Ram Niwas Choudhary[1*], Shweta Gupta[1], Varsha Jeetarwal[1], Manisha Kumawat[1], Naveen Kumar[1], Sachin Saini[2], Pinki Dadarwal[1], H. P. Parewa[3], R. C. Meena[4], S. K. Dadhich[5] and Bheem Parek[1]

[1]Department of Agronomy, RARI Durgapura (SKNAU), Rajasthan, 302018, India
[2]Department of Agronomy, Agriculture University, Jodhpur, 342026, India
[3]College of Horticulture, Durgapura (SKNAU)-Jaipur, 302018, India.
[4]Department of Plant Physiology, RARI Durgapura (SKNAU), Rajasthan, 302018, India
[5]Department of Soil Science & Agricultural Chemistry, RARI Durgapura (SKNAU), Rajasthan, 302018, India
[*]Corresponding author E-mail: rnchoudhary.agro@sknau.ac.in

(Date of Receiving : 24-05-2026; Date of Revision : 10-07-2026; Date of Acceptance : 29-07-2026)

ABSTRACT

Cowpea is slow in its initial growth, so weeds get a long, unhindered start. A field experiment was therefore conducted during the *kharif* seasons of 2024 and 2025 at the Experimental Farm, Rajasthan Agricultural Research Institute, Durgapura, Rajasthan, to test whether the choice of post-emergence herbicide and partial replacement of mineral fertilizer by NPKZn microbial consortium could together improve the growth and yield attributes of cowpea. Treatment consisted of four weed management practices, namely weedy check (W_0), weed free (W_1), sodium acifluorfen 16.5% + clodinafop-propargyl 8% RM at 122.5 g a.i. ha^{-1} (W_2) and propaquizafop 2.5% + imazethapyr 3.75% RM at 125 g a.i. ha^{-1} (W_3), both sprayed 15-20 DAS, which were combined factorially with four nutrient treatments, namely control (M_0), 100% NPKZn (M_1), 75% NPKZn with seed inoculation of NPKZn consortium at 50 g kg^{-1} seed (M_2) and 75% NPKZn with soil application of the consortium at 2 kg ha^{-1} through fortified FYM (M_3), in a factorial randomised block design in three replications. Weed management was non-significant for plant height at 25 DAS but significant in later observation. Pooled over years, W_1 gave the tallest plants at harvest (86.0 cm), the most branches (7.11 plant^{-1}), the largest leaf area at 50 DAS (1281 cm^2), most pods (13.64 plant^{-1}), seeds per pod (8.80) and longest pods (11.13 cm). W_3 was statistically at par with weed free treatment for plant height at harvest, pods per plant, seeds per pod and pod length, and outperformed W_2 throughout; however, test weight remained non-significant to weed management. On the nutrient side, M_2 equalled or exceeded full-dose M_1 for majority of traits, and was significantly superior to it for test weight (9.45 against 8.78 g, a gain of 7.6 %). Seed inoculation also proved to be better than soil application, M_2 exceeding M_3 by 15.1 % in pods per plant and 8.1 % in test weight. Principal component analysis confirmed that the treatments separated along a single vigour axis with W_1M_2 and W_3M_2 at the productive extreme. The findings indicate that propaquizafop + imazethapyr can be a substitute for hand weeding and that a 25 % saving in NPKZn is achievable without yield penalty when the shortfall is covered by seed inoculation with an NPKZn consortium.

***Keywords* :** Cowpea, microbial consortia, post-emergence herbicides, propaquizafop 2.5% + imazethapyr 3.75%, growth attributes, yield attributes.

Introduction

Cowpea [*Vigna unguiculata* (L.) Walp.] is one of the few grain legumes that can be cultivated hot, dry, sandy tracts. It can tolerate drought and heat, can fix useful quantity of atmospheric nitrogen and serves at once as pulse, vegetable, fodder and green manure. In Rajasthan it has long grown as a rainfed *kharif* crop on light-textured soils, where land otherwise would have been kept fallow through the monsoon. Cowpea grain consists about 23 to 25 % protein along with lysine and tryptophan, which are precisely the amino acids that are deficit in cereals (Ahmed *et al*., 2023).

Yet productivity in farmers' fields has been low for long time, and weeds being one of the main reason. Cowpea emerges slowly and is sown at a wide spacing, so the interrow space remains open for *kharif* weeds which favoured by warm, wet soil, take hold of it easily. Critical period of crop-weed competition in cowpea at 20-40 days after sowing (DAS) (Hakeem *et al*., 2025), and Adigun *et al.* (2014) observed that six weeks of clean cultivation brought yields close to that of a season-long weed free crop. The damage is compounded in a legumes, because usually the period of crop weed competition overlaps nodule initiation, so the crop is affected twice over: directly, through competition for light, water and nutrients, and indirectly, through reduced symbiosis and less nodule formation (Jeetarwal *et al*., 2025).

Although hand weeding remains the most effective remedy, but it is still the least available and costly one. Labour charges have increased overtime; labour is becoming scarce during the monsoon and the window for weeding often closes with the rain (Meena and Jeetarwal, 2025). Ready-mix post-emergence herbicides that can control both grasses and broad-leaved weeds in a single spray are the obvious alternative. Sodium acifluorfen, a diphenyl ether that inhibits protoporphyrinogen oxidase (PPO), acts by contact and is paired with clodinafop-propargyl for grass control. Propaquizafop, likewise an acetyl-CoA carboxylase inhibitor, is paired with imazethapyr, an imidazolinone that inhibits acetolactate synthase (ACCase) (Choudhary *et al*., 2026). Both mixtures have performed well in pulses (Malviya and Saini, 2023; Marimuthu *et al.*, 2024), though their ability appears to vary with dose, soil and weed flora, and neither of both have been evaluated for cowpea under the loamy sands of Rajasthan (Jeetarwal *et al*., 2026).

Apart from weed management another big constraint is nutrition, and on these soils, it is not simply a matter of applying more fertilizer. The soils of Rajasthan are low in organic carbon and somewhat saline; so applied phosphorus is rapidly fixed as calcium phosphates, zinc availability is close to deficiency level and potassium release from the mineral fraction is slow. Under such conditions a consortium that combines a nitrogen fixer with phosphate, potassium and zinc solubilising bacteria addresses several bottlenecks at once, and the organisms concerned also secrete indole acetic acid, gibberellins and siderophores, so hormonal benefit is also there rather than only nutritional. It has been observed that generally multi-strain consortia have outperformed single inoculants (Kyei-Boahen *et al.*, 2017). The practically interesting question, is not whether microbial consortia improves growth and yield attributing characters but how much mineral fertilizer it can replace, and whether the method of application *i.e*. seed treatment or soil application (Choudhary *et al*., 2025).

Weed control and microbial nutrition are usually investigated separately: herbicides reshape the biodiversity, whereas microbial consortia help in nutrition and helps develop a vigorous, well-nodulated crop which suppresses late weed flushes without further help. The present study was therefore designed to examine both factors together, and to determine how they improve cowpea productivity in a semi-arid environment.

Materials and Methods

Experimental site and soil

The experiment was conducted at the Experimental Farm, Rajasthan Agricultural Research Institute, Durgapura, Rajasthan, during the *kharif* seasons of 2024 and 2025. It lies in the semi-arid eastern plain zone (Agro-climatic Zone III-A) of Rajasthan at 26°51′ N latitude, 75°47′ E longitude, 390 m above mean sea level. The soil was loamy sand and recorded Bulk density of 1.55 and 1.57 Mg m^{-3} and particle density of 2.63 and 2.66 Mg m^{-3} during 2024 and 2025, respectively. The soil was alkaline in reaction with a pH of 8.20 and 8.22 in 1:2 soil-water suspension and an electrical conductivity of 0.21 and 0.20 dS m^{-1} at 25 °C, low in organic carbon (0.27 and 0.28 %), low in available nitrogen (187.4 and 189.1 kg ha^{-1}), medium in available phosphorus (38.7 and 39.6 kg P_2O_5 ha^{-1}) and medium in available potassium at 208.1 and 208.5 kg K_2O ha^{-1} during 2024 and 2025, respectively. DTPA-extractable zinc, at 0.567 and 0.572 mg kg^{-1}, lay close to the critical limit.

Treatments and design

Weed management practices (4) were combined factorially with microbial consortia treatments (4) to give sixteen combinations and were tested in a factorial randomised block design in three replications, making 48 plots. The gross plot measured 3.6 × 5.0 m and the net plot 3.0 × 4.0 m. The weed management treatments were weedy check (W_0), weed free (W_1), sodium acifluorfen 16.5% + clodinafop-propargyl 8% ready mix at 122.5 g a.i. ha^{-1} (W_2) and propaquizafop 2.5% + imazethapyr 3.75% ready mix at 125 g a.i. ha^{-1} (W_3). Both herbicides were applied as post-emergence sprays at 15-20 DAS. The weedy check was left undisturbed until harvest.

Microbial consortia treatments: control (M_0), 100% NPKZn (M_1), 75 % NPKZn together with seed inoculation of the NPKZn microbial consortium at 50 g kg^{-1} seed (M_2) and 75 % NPKZn together with soil application of the consortium at 2 kg ha^{-1} through FYM fortified at 100 kg ha^{-1} (M_3). The consortium was a carrier-based formulation containing *Rhizobium* sp., *Bacillus* sp., *Serratia* sp. and *Pseudomonas* sp. at a viable count exceeding 10^7 cfu g^{-1}. For seed inoculation the culture was mixed with the seed and the treated seed was shade-dried for about thirty minutes before sowing; for soil application the culture was blended with well-decomposed farmyard manure, incubated for 2 days and broadcast at sowing.

Crop management

Cowpea variety CPD-119 was sown at 30 × 10 cm spacing using a seed rate of 20 kg ha^{-1}. The crop was raised on monsoon rainfall supplemented by 1 lifesaving irrigation where required. Plant protection measures were applied uniformly across all plots as and when necessary, and all other operations followed the recommended package of practices for the zone.

Observations recorded

Five plants were tagged at random within the net plot of each experimental unit. Plant height was measured from the ground surface to the tip of the uppermost fully opened leaf at 25 DAS, 50 DAS and at harvest. Branches per plant were counted at harvest. Leaf area per plant was recorded at 25 and 50 DAS with a leaf area meter and expressed in cm^2. At harvest the number of pods per plant and the number of seeds per pod were counted from the tagged plants, and pod length was measured from pods drawn at random from them.

Statistical analysis

Data from the two seasons were first analysed separately. Since none of the treatment × year interactions reached significance, the two years were pooled and analysed together following the procedure for a factorial randomised block design given by Gomez and Gomez (1984), The F-test was applied at the 5 per cent level and critical differences were worked out only where the F-test proved significant; means sharing a common superscript within a column are statistically at par. Principal component analysis was performed using R studio on the standardised pooled means and the first two components were displayed as a biplot. All computations were carried out in R statistical software (RStudio 2026.06.0 Build 242) using the *agricolae* package.

Results and Discussion

Growth attributes

Plant height

The response of plant height to weed management changed with crop age (Table 1). At 25 DAS effect was non-significant. At 25 DAS the weeds rarely begun to accumulate biomass and the herbicides had been sprayed only five to ten days earlier. At 50 DAS highest pooled height was recorded under W_1 (68.3 cm), followed by W_3 (63.3 cm) and W_2 (57.6 cm), each differing significantly from the other and from the weedy check at 51.0 cm; the weed free recoded 33.9 % improvement over weedy check. At harvest W_1 (86.0 cm) and W_3 (82.4 cm) were statistically at par, against 65.1 cm in the weedy check, and showed improvement of 32.1 and 26.6 % respectively. The same trend was observed under both seasons.

Propaquizafop + Imazethapyr at par with hand weeding by harvest, whereas Sodium Acifluorfen + Clodinafop did not. Possible reason can be the slight phytotoxicity of Sodium acifluorfen as it is a contact herbicide that generates reactive oxygen in illuminated tissue and typically bronzes or scorches legume foliage for initial week or two after spraying, so some of the advantage it gains against weeds is reciprocated back in crop injury. The other advantage is persistence of imazethapyr that helps it carrying some residual activity in the soil and help continues to suppress later flushes, while the contact chemistry of acifluorfen offers nothing once the spray has dried and plant has died. Malviya and Saini (2023) reported the same superiority of the propaquizafop + imazethapyr mixture against mixed weed flora in blackgram. Similar results also reported by Charitha *et* al., (2024), Jain and Jain, (2025), Kumar *et al*. (2025) and Meena *et al*. (2026)

Microbial consortia influenced plant height at every stage. Pooled height at 25 DAS was highest under M_2 (25.5 cm) while being at par with M_1 (25.0 cm) and significantly above the control (22.7 cm), recording an improvement of 12.3 %. That lead was also maintained at 50 DAS (63.4 cm) and at harvest (80.3 cm), leading to increase of 14.0 and 13.1 % over M_0. The most important comparison, though, is not against M_0 but against M_1. M_2 carried 25% less mineral fertilizer, yet was statistically at par with the full dose at every stage, and even numerically ahead of it. M_3 behaved similarly. In other words, the consortium helped met the deficiency created due to withdrawing of 25 % NPKZn, and that also from the first fortnight onward, well before nodules could have become functional. This early response can be credited to hormonal mechanism rather than a nutritional as the phosphate and zinc solubilising members of such consortia are also prolific producers of indole acetic acid, which helps in cell elongation and root proliferation. Once nodulation is established the nitrogen supply is fulfilled by it. Comparable height responses to inoculation in cowpea have been recorded by Kandil and Özdamar Ünlü, (2023), Danso *et al*. (2025) and Jaybhay *et al*., (2025)

Number of branches per plant

Pooled over years, W_1 recorded highest (7.11) branches per plant against 4.62 under weedy check, a difference of 53.9 % (Table 1). W_3 (6.47) and W_2 (6.25) fell in between and were at par with each other, but both significantly lower than weed free treatment. Branch development depends on the release of axillary buds from apical dominance, and that release is largely governed by the ratio of red to far red light reaching the lower canopy. Light reflected from a weedy stand is enriched in far-red, so the buds stay dormant. This phytochrome-mediated pathway explains why branching responds so much more drastically to weed removal than height does, and it also helps in understanding why neither herbicide could not match hand weeding here. Similar results also observed by Dhakad *et al*. (2025), Giri*et et al*. (2025) and Jain and Jain (2025)

In microbial consortia treatments, M_2 recorded 6.57 branches per plant as against 5.38 in the control, increase of 22.1 %, with M_1 (6.30) and M_3 (6.20) at par with it. A better nourished plant carries a larger assimilate reserve to place where branch initiation occurs, and proper zinc content supports tryptophan and hence auxin metabolism, which help regulates bud growth. The equivalence of the three fertilised treatments again indicates that 75 % NPKZn supplemented by the consortium was sufficient for proper branching. Similar results also reported by Das *et al*. (2025) and Jaybhay *et al*. (2025)

Leaf area

At 25 DAS pooled leaf area under W_1 was 453 cm^2 $plant^{-1}$ against 426 cm^2 in the weedy check, showing significant improvement of 6.3 %, with W_2 (443 cm^2) and W_3 (448 cm^2) at par with both (Table 1). Similarly, at 50 DAS W_1 recorded 1281 cm^2 $plant^{-1}$, significantly superior to W_3 (1203 cm^2) and W_2 (1173 cm^2), which were at par with each other, and significantly superior over weedy check at 994 cm^2; the improvement over the weedy check was 28.9, 21.0 and 18.0 % respectively. Among the microbial consortia treatments M_2 (1214 cm^2) was 13.9 % higher than control, while M_1 (1173 cm^2) and M_3 (1198 cm^2) being at par. Leaf area is the physical basis of light interception, and the two factors were definitely improving the same photosynthetic machinery by different routes, weed removal improves by conserving the water and nutrients needed to expand and retain leaves, while improved nutrition especially the nitrogen supply helps in leaf expansion and chlorophyll content. Similar results also reported by Malaie *et al*. (2026)

Yield attributes

Number of pods per plant

Pods per plant responded more strongly to both factors than any other yield attribute (Table 2). Pooled over the two seasons, W_1 produced highest no of pods per plant (13.64) and was significantly superior over rest except W_3 (12.69). W_1 and W_3 recorded increase of 53.8 and 43.1 % over weedy check. Since number of pods mainly depends on the number of fertile branches and by the plant's ability to retain flowers, the close relation between number of branching and the pod data is easily understood. Weed competition at the time of flowering aggravates flower and at later stages causes abscission of young pods, because a moisture-stressed legume sheds reproductive structures before it sacrificing leaves. The practical point is that a single post-emergence spray of propaquizafop + imazethapyr improved pod numbers as comparable to a season of hand weeding, that also at a fraction of the labour cost.

Treatment M_2 recorded 13.27 pods per plant compared to 9.49 in the control, showing an increase of 39.8 %, and was at par with the M_1 (12.49) despite carrying 25 % less fertilizer. M_3 (11.53), however, was significantly lower than M_2, but remaining at par with M_1. Seed inoculation with microbial consortia places the organisms directly near seed coat, so colonisation of emerging radicle begins within hours of imbibition and the rhizosphere is occupied by them before competing soil microflora can even establish. Consortium applied through fortified farmyard manure has to survive dispersal through a large volume of soil and struggle to find the root. On a low organic carbon loamy sand of Rajasthan with pH 8.2, the odds are not favourable. Similar results were also reported by Kyei-Boahen *et al*. (2017) and Aulakh *et al*. (2023)

Number of seeds per pod

Highest number of seeds per pod observed under W_1 (8.80), which was at par with W_3 (8.32), and lowest recorded under weedy check (6.94), W_1 recorded an improvement of 26.8 % over weedy check (Table 2). Among the nutrient treatments M_2 recorded 8.61 seeds per pod against 7.16 in the control, an increase of 20.3%, and was at par with M_1 (8.14) but significantly superior to M_3 (7.84). Seed set within a pod depends on ovule fertilisation and on the plant's ability to nourish the developing embryos after anthesis. If a crop is deficit of nutrients or moisture in that window then a significant proportion of ovule aborts. Both proper weed management and improved nutrition act on precisely firstly by preserving soil moisture and the secondly by maintaining proper nutritional supply at critical stage when nodule activity would otherwise begin to decline Jaybhay *et al*. (2025) also reported similar results.

Pod length

Pooled pod length was longest under W_1 (11.13 cm) which was at par with W_3 (10.50 cm) while lowest recorded under weedy check (8.29 cm), W_1 and W_3 recorded an increase of 34.3 and 26.7 % respectively over weed check (Table 2). W_2 recorded 9.07 cm and, did not differ significantly from the weedy check. Among the microbial consortia treatments, pod length increased from 8.56 cm in the control to 10.50 cm under M_2, an increase of 22.7 %, with M_1 (10.10 cm) and M_3 (9.84 cm) at par. Pod elongation takes place mainly in the next ten days following fertilisation and is a cell expansion process, so it simply responds to turgor pressure and to auxin and gibberellin supply, which is why phytohormone producing microbial consortia influence it as readily as mineral nutrition does. Similar results were also reported by Kyei-Boahen *et al*. (2017) and Aulakh *et al*. (2023)

Test weight

Test weight was the one character that weed management failed to influence, pooled values lying within a narrow range of 8.47 to 8.92 g (Table 2). Individual seed weight in cowpea is among highly heritable characterstics of plant. When assimilate become scare it reduces the number of pods and the number of seeds rather than compromising the size of those. This hierarchy of sink priority is well established in grain legumes and explains why test weight is usually the last yield component to respond to weed management. Gunasekaran *et al.* (2024) likewise found no significant difference in 100-seed weight among weed control treatments in blackgram.

M_2 recorded 9.45 g which was significantly superior all and 20.1 % above the control (7.87 g). M_1 (8.78 g) and M_3 (8.74 g), which were at par with one other. Seed inoculation combined with 75 % NPKZn did not just match the full mineral dose, it exceeded it by 7.6 % for the character most directly governed by mineral nutrition. Seed filling is the stage at which demand for nutrients (especially phosphorus and zinc) peaks, phosphorus for the phospholipid and phytate laid down in the cotyledons whereas, zinc for the enzymes governing carbohydrate and protein synthesis in the developing seed. A basal application of soluble phosphate on an alkaline soil is usually fixed within weeks of application and is largely unavailable by the time that demand arrives, whereas a colonised rhizosphere continues to mobilise phosphorus and zinc from fixed pools throughout the reproductive phase. Applying the consortium through fortified farmyard manure achieved less advantage as compared to seed inoculation, which supports the conclusion drawn from the pod data that the delivery route, and not just the presence of the organisms, determines the outcome. Similar results were also reported by Kyei-Boahen *et al*. (2017) and Aulakh *et al*. (2023)

Weed management determines how many sinks the plant establishes, since it governed branches, pods, seeds per pod and pod length but not seed size. Nutrient management, and specifically the consortium delivered on the seed, determines how well those sinks are filled, since it alone moved test weight. Neither factor substitutes for the other, which is precisely why they were worth studying together.

Principal component analysis

The PCA biplot revealed that the first two principal components (PC1 and PC2) together accounted for 68.2% of the total variation in the dataset (Fig. 1). PC1 explained the major proportion of variation (58.8%), whereas PC2 contributed 9.4%. Most of the growth and yield attributes, including plant height at 50 DAS (PH50), branches plant^{-1} (BPP), pods plant^{-1} (PPP), pod length (PL), 100-seed weight (SW100), leaf area at 50 DAS (LA50) and plant height at harvest (PHH), were positively associated with PC1. Whereas, in contrast, plant height and leaf area at 25 DAS (PH25 and LA25) showed a stronger association with PC2. The position of the treatment combinations in relation to the trait vectors indicated their association with the corresponding growth and yield attributes. Overall, the PCA demonstrated that PC1 was the principal axis governing the major variation in growth and yield performance of cowpea, while PC2 represented a smaller, additional component of variation.

Interaction effect

The interaction between weed management practices and microbial consortia was non-significant for all the growth and yield attributes studied, indicating that the two factors operated independently and that the benefit of consortium inoculation was realised irrespective of the weed management practice adopted.

Conclusion

After two seasons of experimentation at Durgapura we can conclude two things. First, propaquizafop 2.5% + imazethapyr 3.75% at 125 g a.i. ha^{-1}, sprayed once at 15 to 20 DAS, proved to be as effective as weed free for plant height at harvest, pods per plant, seeds per pod and pod length, and consistently remain superior to sodium acifluorfen 16.5% + clodinafop-propargyl 8% at 122.5 g a.i. ha^{-1}. Places where labour is scarce and costly, it serves as a substitute for hand weeding. Second, a quarter of the fertilizer dose of NPKZn can be withdrawn without any significant reduction if seed inoculation with the NPKZn microbial consortium at 50 g kg^{-1} seed is used; this treatment equalled the full mineral dose for every character measured and surpassed it by 7.6 % for test weight. Applying the same consortium through fortified farmyard manure also permitted the 25 % saving but provided none additional benefit, so the route of application matters. Combining propaquizafop + imazethapyr with seed inoculation therefore offers cowpea growers in semi-arid eastern Rajasthan a route to higher productivity that is cheaper in both labour and fertilizer than current practice.

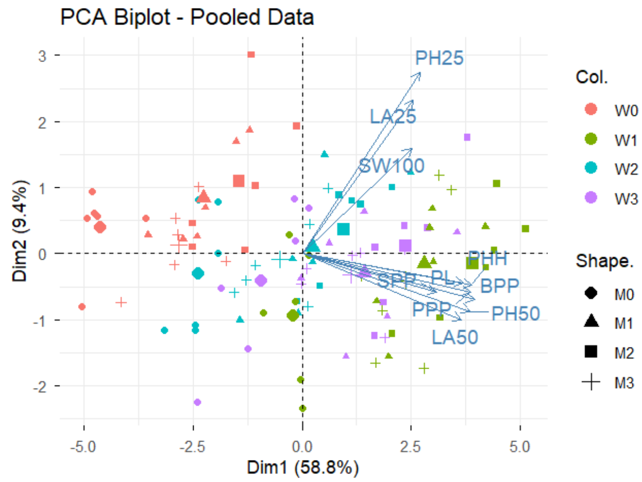

Fig. 1: Principal component analysis biplot showing the association among growth and yield attributes of cowpea under different weed management and microbial consortia treatments (pooled data of 2024 and 2025)

Table 1 : Effect of weed management practices and microbial consortia on growth attributes of cowpea (2024, 2025 and pooled).

Treatments	Plant height (cm)									Branches $plant^{-1}$			Leaf area (cm^2)					
	25 DAS			50 DAS			At harvest			At harvest			25 DAS			50 DAS		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
A. Weed management																		
W_0	24.1^a	23.1^a	23.6^a	52.5^c	49.4^c	51.0^d	65.8^c	64.4^c	65.1^c	4.77^c	4.48^c	4.62^c	420^a	432^a	426^b	987^c	1002^c	994^c
W_1	25.8^a	24.4^a	25.1^a	69.1^a	67.5^a	68.3^a	87.0^a	85.1^a	86.0^a	7.25^a	6.97^a	7.11^a	446^a	461^a	453^a	1256^a	1305^a	1281^a
W_2	24.3^a	23.5^a	23.9^a	58.4^{bc}	56.8^b	57.6^c	74.6^b	71.7^b	73.1^b	6.35^b	6.14^b	6.25^b	438^a	447^a	443^{ab}	1152^b	1193^b	1173^b
W_3	24.7^a	24.2^a	24.4^a	64.3^{ab}	62.4^a	63.3^b	83.2^a	81.6^a	82.4^a	6.53^b	6.41^{ab}	6.47^b	441^a	454^a	448^{ab}	1186^{ab}	1219^{ab}	1203^b
SEm ±	0.68	0.66	0.47	1.55	1.35	1.03	1.79	1.84	1.28	0.17	0.15	0.11	9.93	10.43	7.20	26.15	28.60	19.38
B. Microbial consortia																		
M_0	23.2^b	22.2^b	22.7^c	56.3^b	54.9^b	55.6^b	71.3^b	70.7^b	71.0^b	5.49^b	5.26^b	5.38^b	423^a	430^a	426^b	1025^b	1106^b	1066^b
M_1	25.5^{ab}	24.5^{ab}	25.0^{ab}	62.1^{ab}	60.0^{ab}	61.0^a	80.4^a	77.1^{ab}	78.8^a	6.41^a	6.19^a	6.30^a	441^a	453^a	447^{ab}	1166^a	1180^{ab}	1173^a
M_2	26.2^a	24.9^a	25.5^a	64.9^a	62.0^a	63.4^a	81.9^a	78.7^a	80.3^a	6.72^a	6.42^a	6.57^a	447^a	461^a	454^a	1202^a	1225^a	1214^a
M_3	24.1^{ab}	23.7^{ab}	23.9^{bc}	61.1^{ab}	59.2^{ab}	60.2^a	76.9^{ab}	76.2^{ab}	76.6^a	6.28^a	6.13^a	6.20^a	433^a	450^a	442^{ab}	1187^a	1208^{ab}	1198^a
SEm ±	0.68	0.66	0.47	1.55	1.35	1.03	1.79	1.84	1.28	0.17	0.15	0.11	9.93	10.43	7.20	26.15	28.60	19.38

W_0 = weedy check; W_1 = weed free; W_2 = sodium acifluorfen 16.5% + clodinafop-propargyl 8% RM at 122.5 g a.i. ha^{-1} at 15-20 DAS; W_3 = propaquizafop 2.5% + imazethapyr 3.75% RM at 125 g a.i. ha^{-1} at 15-20 DAS. M_0 = control; M_1 = 100% NPKZn; M_2 = 75% NPKZn + seed inoculation with NPKZn microbial consortia at 50 g kg^{-1} seed; M_3 = 75% NPKZn + soil application of NPKZn microbial consortia (2 kg ha^{-1}) fortified FYM at 100 kg ha^{-1}.

Table 2 : Effect of weed management practices and microbial consortia on yield attributes of cowpea (2024, 2025 and pooled).

Treatments	Pods $plant^{-1}$			Seeds pod^{-1}			Pod length (cm)			100-seed weight (g)		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
A. Weed management												
W_0	9.34^c	8.40^c	8.87^c	7.16^c	6.72^c	6.94^c	8.56^c	8.03^b	8.29^b	8.65^a	8.29^a	8.47^a
W_1	13.83^a	13.46^a	13.64^a	9.00^a	8.59^a	8.80^a	11.20^a	11.07^a	11.13^a	9.05^a	8.78^a	8.92^a
W_2	11.81^b	11.33^b	11.57^b	7.83^{bc}	7.55^{bc}	7.69^b	9.48^{bc}	8.66^b	9.07^b	8.81^a	8.50^a	8.66^a
W_3	12.97^{ab}	12.42^{ab}	12.69^a	8.48^{ab}	8.16^{ab}	8.32^{ab}	10.60^{ab}	10.41^a	10.50^a	8.99^a	8.58^a	8.78^a
SEm ±	0.44	0.41	0.30	0.28	0.23	0.18	0.36	0.32	0.24	0.26	0.25	0.18
B. Microbial consortia												
M_0	9.52^b	9.47^c	9.49^c	7.31^b	7.00^b	7.16^c	8.72^b	8.39^b	8.56^b	8.08^b	7.66^b	7.87^c

Treatments	Pods plant^{-1}			Seeds pod^{-1}			Pod length (cm)			100-seed weight (g)		
	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled	2024	2025	Pooled
M_1	12.96^a	12.02^{ab}	12.49^{ab}	8.28^{ab}	8.01^a	8.14^{ab}	10.38^a	9.82^a	10.10^a	8.91^{ab}	8.64^a	8.78^b
M_2	13.49^a	13.05^a	13.27^a	8.80^a	8.42^a	8.61^a	10.68^a	10.32^a	10.50^a	9.63^a	9.27^a	9.45^a
M_3	11.98^a	11.07^b	11.53^b	8.08^{ab}	7.60^{ab}	7.84^{bc}	10.05^{ab}	9.63^a	9.84^a	8.89^{ab}	8.58^{ab}	8.74^b
SEm ±	0.44	0.41	0.30	0.28	0.23	0.18	0.36	0.32	0.24	0.26	0.25	0.18

W_0 = weedy check; W_1 = weed free; W_2 = sodium acifluorfen 16.5% + clodinafop-propargyl 8% RM at 122.5 g a.i. ha^{-1} at 15-20 DAS; W_3 = propaquizafop 2.5% + imazethapyr 3.75% RM at 125 g a.i. ha^{-1} at 15-20 DAS. M_0 = control; M_1 = 100% NPKZn; M_2 = 75% NPKZn + seed inoculation with NPKZn microbial consortia at 50 g kg^{-1} seed; M_3 = 75% NPKZn + soil application of NPKZn microbial consortia (2 kg ha^{-1}) fortified FYM at 100 kg ha^{-1}.

Acknowledgement

The authors gratefully acknowledge Rajasthan Agricultural Research Institute, Durgapura, for the field and laboratory facilities extended during this investigation.

Competing interests

The authors declare that they have no competing interests.

Declaration on the use of generative artificial intelligence

Use of Grammarly was done to check for grammatical mistakes.

References

Adigun, J., Osipitan A.O., Lagoke S.T., Adeyemi R.O. and Afolami S.O. (2014). Growth and yield performance of cowpea (*Vigna unguiculata* (L.) Walp.) as influenced by row-spacing and period of weed interference in South-West Nigeria. *Journal of Agricultural Science*, **6(4)**, 188-198.

Ahmed, H. G. M. D., Naeem, M., Faisal, A., Fatima, N., Tariq, S., and Owais, M. (2023). Enriching the content of proteins and essential amino acids in legumes. In *Legumes biofortification* (pp. 417-447). Cham: Springer International Publishing.

Aulakh, A. M., Qadir, G., Hassan, F. U., Hayat, R., Sultan, T., Bibi, R., and Malik, S. N. (2023). Role of resilient soil microbial consortia on growth and yield attributes of chickpea under water stress. *Egyptian Journal of Agronomy*, **45(1)**, 99-110.

Charitha, N., Madhavi, M., Pratibha, G., and Ramprakash, T. (2024). Effect of integrated weed management practices on growth parameters, yield attributes, and yield of Rabi groundnut. *International Journal of Research in Agronomy*, ***7*(4)**, 668-671.

Choudhary, M., Prasad, M., and Mahawer, S. K. 2025. Nutrient Management Strategies for Sustainable Forage Production. *Indian Journal of Fertilisers*, **21(11)**, 1160-1169.

Choudhary, R. N., Gupta, S., Jeetarwal, V., Saini, S., Parshar, V., Bohi, S. P., Prajapat, V., and Parewa, H. P. 2026. Herbicide resistance in weeds: Evolution, mechanisms and agronomic mitigation strategies. *Journal of Advances in Biology & Biotechnology*, **29(4),** 86-96. 10.9734/jabb/2026/v29i43772

Danso, J., Ulzen, J., Ahenkan, M., Ulzen, O. O., Asei, R., Sarkodie Addo, J., and Appiah Agyei, C. (2025). Growth and yield response of cowpea [*Vigna unguiculata* (L.) Walp.] to nitrogen fertilizer and inoculant application. *Agrosystems, Geosciences & Environment*, **8(4)**, e70237.

Das, T., Mahapatra, S., Rayanoothala, P., Alam, S. H., Sen, A., and Mondal, S. (2025). Native microbial consortia effect on vigour index and growth promotion of lentil isolated from indo-gangetic plains. *National Academy Science Letters*, **48(4)**, 497-501.

Dhakad, U., Jadon, C. K., Yadav, S. L., and Meena, S. N. (2025). Bio-efficacy evaluation of herbicides alone and mixtures on weed dynamics, growth, yield and economics of soybean (*Glycine max* l. Merrill) and their residual effect on succeeding wheat. *Plant Archives (09725210)*, **25(1)**.

Giri, M., Jaybhaye, C., & Kanwade, D. (2025). Evaluation of Pre and Post-emergence Herbicides for Weed Management in Soybean (*Glycine max*). *Indian Journal of Agronomy*, **70(3)**, 299-305.

Hakeem, S. A., Matloob, A., Ghazy, A. H., Fiaz, S., Ali, M., Haq, T. U., and Ul Haq, M. Z. (2025). Critical period of weed-crop competition in irrigated chickpea as a tool for judicious weed control. *Scientific Reports*, **15*(1)***, 32116.

Jain, L. K., and Jain, A. (2025). Efficacy of herbicides on weed parameters and yield of greengram [*Vigna radiata* Wiljeck]. *Indian Journal of Agronomy*, **70(1)**, 99-104.

Jaybhay, S. A., Suresha, P. G., Tetali, S. P., and Idhol, B. D. (2025). Exploring the combined effect of microbial consortia and fertilizers on growth and yield of soybean [*Glycine max* (L.) Merrill.]. *Legume Research-An International Journal*, **1(7)**.

Jeetarwal, V., Singh, S. P., and Saini, S. 2025. Effect of different herbicides on weed dynamics in green gram under western arid region of Rajasthan. *Annals of Agricultural Research* **46 (3)**: 280-285. https://epubs.icar.org.in/index.php/AAR/article/view/172659

Jeetarwal, V., Singh, S. P., Saini, S., Yadav, M., Jeetarwal, P., and Nitharwal, P. K. (2026). Effect of pre-and post-emergence herbicides on crop growth, yield and profitability of greengram under western arid region of Rajasthan. *Annals of Agricultural Research* **47(1)**:79-84.

Kandil, A. E., and Özdamar Ünlü, H. (2023). Effect of rhizobium inoculation on yield and some quality properties of fresh cowpea. *Cogent Food & Agriculture*, **9(2)**, 2275410.

Kumar, P., Virk, H. K., Singh, M., and Bola, S. S. (2025). Optimizing post-emergence herbicide rates for enhanced growth, symbiotic efficiency and weed management in soybean (Glycine max). *Indian Journal of Agronomy*, **70(4)**, 489-493.

Kyei-Boahen, S., Savala, C. E., Chikoye, D., and Abaidoo, R. (2017). Growth and yield responses of cowpea to inoculation and phosphorus fertilization in different environments. *Frontiers in plant science*, **8**, 646.

Malaie, S., Pourakbar, L., Moghaddam, S. S., and Khezrinejad, N. (2026). Microbial Consortia and Biochar Enhance Photosynthesis, Water Relations, and Leaf Thermal Regulation in Vigna radiata L.

Malviya, S., and Saini, M. K. (2023). Effect of Herbicide (Propaquizafop and Imazethapyr) on Weed Flora Associated with Blackgram in Central India. *International Journal of Environment and Climate Change*, **13(10)**, 675–686. https://doi.org/10.9734/ijecc/2023/v13i102703

Marimuthu, S., Gunasekaran, M., Parimaladevi, R., Subrahmaniyan, K., Byrareddy, V. M., Mushtaq, S., and Dhanalakshmi, A. (2024). Effective weed control through post-emergence herbicides to enhance blackgram (*Vigna mungo* L.) productivity in South India. *Scientific reports*, **14(1)**, 26468.

Meena, B. L., Meena, D. S., Meena, R. K., & Meena, H. (2026). Effect of Pre-and Post-Emergence Herbicides on Weed Biomass, Nutrient Depletion, and Growth of Soybean in Humid South-Eastern Plains of Rajasthan. *Indian Journal of Ecology*, **52(5)**, 972-974.

Meena, B. R., and Jeetarwal, V. 2025. Weed control methods affect weed dynamics, productivity and economics of clusterbean [*Cyamopsis tetragonoloba* (L.) Taub.]. *Annals of Agricultural Research* **46 (1)**, 65-70.