Great Britain Journals Press

RESEARCH FINGERPRINT

IDENTIFIER
LJRS-227746

PEER REVIEW
Double Blind

SIMILARITY CHECK
Perplexity AI and iThenticate

ACCESS
Open Access

LANGUAGE
English

PRINT ISSN
2631-8490

ONLINE ISSN
2631-8504

EDITION

ABBREVIATION
LJRS

VOLUME
26

ISSUE
5

YEAR
2026

KEY DATES

RECEIVED
2026-05-09

ACCEPTED
2026-05-20

ONLINE PUBLISHED
2026-06-19

PUBLISHED
2026-05-30

CATALOGING

CROSSMARK DOI
10.34257/LJRS227746UK

ACCESS ONLINE

London Journal of Research In Science: Natural and Formal
General Section

Article Record

Foliar Application of Gehna Super Bio-stimulant Enhances Growth, Yield, and Nutrient Uptake in Maize (Zea mays L.) under South Indian Agroclimatic Conditions

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ABSTRACT

Bio-stimulants represent a rapidly growing category of agronomic inputs that improve crop performance under both optimal and sub-optimal growing conditions. In this study, we evaluated the agronomic efficacy and economic viability of Gehna Super, a commercial plant bio-stimulant, applied as a foliar spray at four concentrations (2, 2.5, 3, and 5 ml L^{-1} water) on maize (Zea mays L.) during Kharif 2022 at the University of Agricultural Sciences (UAS), GKVK, Bangalore. A randomized complete block design (RCBD) with five treatments replicated four times was employed. Gehna Super significantly enhanced plant height, leaf area index (LAI), total dry matter accumulation, cob length, kernel number, kernel yield, and N–P–K uptake compared to untreated control. Foliar spray at 5 ml L^{-1} (T5) recorded the highest kernel yield (8,369 kg ha^{-1}; +36.9% over control) and total dry matter at harvest (463.16 g $plant^{-1}$). However, application at 3 ml L^{-1} (T4) delivered the most favorable cost–benefit ratio (1:3.42). No phytotoxic effects were observed at any dose. Results indicate that Gehna Super at 2.5–3 ml L^{-1} represents the optimal dose for maximizing economic returns in maize production under Eastern Dry Zone conditions of Karnataka, India.

Index Terms: bio-stimulant • Gehna Super • Zea mays • foliar spray • crop growth • kernel yield • nutrient uptake • cost–benefit ratio

FUNDING
This research was supported by Meenakshi Agro Chemicals, Hyderabad, India, which provided the...

CONFLICTS
The author declares no conflict of interest.

AI USAGE
No generative AI was used for analysis or results.

HOW TO CITE
Somashekar et al. (2026). Foliar Application of Gehna Super Bio-stimulant Enhances Growth, Yield, and Nutrient Uptake in Maize (Zea mays L.) under South Indian Agroclimatic Conditions. London Journal of Research In Science: Natural and Formal, 26(5), 31-39. DOI: 10.34257/LJRS227746UK

METADATA CONTINUATION

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FULL FUNDING STATEMENT

This research was supported by Meenakshi Agro Chemicals, Hyderabad, India, which provided the experimental product. The funder had no role in study design, data collection, analysis, interpretation, or decision to publish.

ARCHIVAL RECORD

LJRS · Vol 26 · Issue 5 · 2026

Article ID LJRS-227746 · DOI 10.34257/LJRS227746UK

Print ISSN 2631-8490 · Online ISSN 2631-8504

RESEARCH ARTICLE

Foliar Application of Gehna Super Bio-stimulant Enhances Growth, Yield, and Nutrient Uptake in Maize (Zea mays L.) under South Indian Agroclimatic Conditions

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Abstract

Bio-stimulants represent a rapidly growing category of agronomic inputs that improve crop performance under both optimal and sub-optimal growing conditions. In this study, we evaluated the agronomic efficacy and economic viability of Gehna Super, a commercial plant bio-stimulant, applied as a foliar spray at four concentrations (2, 2.5, 3, and 5 ml L^{-1} water) on maize (Zea mays L.) during Kharif 2022 at the University of Agricultural Sciences (UAS), GKVK, Bangalore. A randomized complete block design (RCBD) with five treatments replicated four times was employed. Gehna Super significantly enhanced plant height, leaf area index (LAI), total dry matter accumulation, cob length, kernel number, kernel yield, and N–P–K uptake compared to untreated control. Foliar spray at 5 ml L^{-1} (T5) recorded the highest kernel yield (8,369 kg ha^{-1}; +36.9% over control) and total dry matter at harvest (463.16 g plant^{-1}). However, application at 3 ml L^{-1} (T4) delivered the most favorable cost–benefit ratio (1:3.42). No phytotoxic effects were observed at any dose. Results indicate that Gehna Super at 2.5–3 ml L^{-1} represents the optimal dose for maximizing economic returns in maize production under Eastern Dry Zone conditions of Karnataka, India.

Keywords: *bio-stimulant, Gehna Super, Zea mays, foliar spray, crop growth, kernel yield, nutrient uptake, cost–benefit ratio*

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1 Introduction

Maize (Zea mays L.) is the third most important cereal crop globally and the highest-yielding food grain crop in India, where it is grown across diverse agroclimatic zones on approximately 8.7 million hectares. In Karnataka, maize occupies a prominent position in the Kharif cropping system of the Eastern Dry Zone, a semi-arid agroclimatic region characterized by red sandy loam soils of low to medium fertility. Achieving sustainable yield improvement in this environment requires strategies that increase nutrient use efficiency, enhance canopy development, and strengthen reproductive performance without increasing the ecological footprint of production.

Plant bio-stimulants are defined by the European Biostimulant Industry Council as ”substances or microorganisms that, when applied to plants or the rhizosphere, stimulate natural processes to enhance nutrient use efficiency, abiotic stress tolerance, quality traits, and/or availability of confined nutrients in the soil”. These products include humic and fulvic acids, protein hydrolysates, seaweed extracts, and trace-element formulations. Their application as foliar sprays exploits the rapid uptake and systemic distribution of bioactive molecules through leaf stomata and cuticle, bypassing soil-mediated constraints such as nutrient fixation and microbial decomposition.

Gehna Super is a proprietary poly-nutrient, plant growth-promoting bio-stimulant manufactured by Meenakshi Agro Chemicals, Hyderabad, India. While several studies have documented yield benefits of generic bio-stimulants in cereals (Bulgari *et al.*, 2015; du Jardin, 2015; Van Oosten *et al.*, 2017), there is a paucity of replicated field data on the dose–response relationship of this formulation in maize under South Indian conditions. Establishing such evidence is critical for product registration, extension advisory, and farmer adoption.

The present investigation was therefore designed to: (i) assess the effect of Gehna Super at escalating concentrations on vegetative growth, dry matter accumulation, yield attributes, and grain yield of maize; (ii) quantify nutrient (N, P, K) uptake in response to bio-stimulant application; and (iii) determine the most economically viable application dose through cost–benefit analysis. We hypothesized that foliar application of Gehna Super would dose-dependently improve key agromorphological traits and that an intermediate concentration would optimize economic returns.

2 Materials and methods

2.1 Experimental Site and Soil characteristics

The field experiment was conducted during Kharif 2022 at the All India Coordinated Research Project (AICRP) on Sunflower, Zonal Agricultural Research Institute (ZARS), Gandhi Krishi Vigyan Kendra (GKVK), University of Agricultural Sciences (UAS), Bangalore. The site is located at 13°05′ N latitude and 77°34′ E longitude, at an altitude of 924 m above mean sea level, within Agroclimatic Zone V (Eastern Dry Zone) of Karnataka.

The soil was red sandy loam (Alfisol order) with the following physicochemical properties: coarse sand 53.4%, fine sand 14.8%, silt 16.6%, clay 15.2%; pH 5.89 (mildly acidic); electrical conductivity 0.35 dS m^{-1}; organic carbon 0.48%; available N 239.04 kg ha^{-1} (low), available P 25.13 kg ha^{-1} (medium), and available K 248.31 kg ha^{-1} (medium). These characteristics are representative of rain-fed maize-growing soils in the Eastern Dry Zone.

2.2 Climatic conditions

The experimental site receives a mean annual rainfall of 1,328.4 mm, predominantly from June to November. During the cropping season (July–October 2022), total rainfall was 864.2 mm with a peak in October (361.0 mm). The mean maximum temperature ranged from 27.0 to 27.7 °C and mean minimum temperature from 16.9 to 18.7 °C. Maximum relative humidity ranged between 90 and 91%, and minimum relative humidity between 59 and 62%. These conditions provided adequate moisture for rainfed maize production without water-logging stress.

2.3 Experimental design and Treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) with five treatments replicated four times (20 plots total). Each plot measured 5.0 m × 5.0 m (25 m^2), with 0.5 m buffer bunds between adjacent plots and 1.0 m alleyways between replications. Maize seeds (commercial variety) were sown on 15 July 2022 at a spacing of 50 cm × 30 cm using the dibbling method. The following treatments were evaluated:

T1: Untreated control (no bio-stimulant)
T2: Gehna Super foliar spray @ 2 ml L^{-1} of water
T3: Gehna Super foliar spray @ 2.5 ml L^{-1} of water
T4: Gehna Super foliar spray @ 3 ml L^{-1} of water
T5: Gehna Super foliar spray @ 5 ml L^{-1} of water

Foliar sprays were applied four times at 30, 45, 60, and 75 days after sowing (DAS) using a hand-operated knapsack sprayer with a flat-fan nozzle, ensuring uniform coverage of the crop canopy. The recommended dose of farm yard manure (FYM) was incorporated one week before sowing, and NPK fertilizers (DAP and muriate of potash) were applied as per crop requirements. Two hand weedings were performed at 15 and 30 DAS, followed by earthing-up at 30 DAS. Gap-filling was carried out two weeks after sowing to maintain optimum plant population.

2.4 Observations Recorded

Growth parameters. Ten randomly selected plants per plot were tagged for biometric measurements at 30, 45, 60, 75, and 90 DAS. Plant height was measured from the base to the tip of the newly emerged leaf using a measuring tape. Leaf count was performed manually. Leaf area per plant was measured using a leaf area meter; leaf area index (LAI) was computed as leaf area per plant divided by land area per plant (0.15 m^2). Leaf, stem, and cob dry weights were determined after oven-drying at 65 °C to constant weight; total dry matter (TDM) was the sum of all components.

Yield and yield attributes. At harvest, ten randomly selected plants per plot were assessed for number of cobs per plant, cob length (cm), cob girth (cm), number of rows per cob, number of kernels per row, number of kernels per cob, kernel weight per cob (g), and test weight (100-kernel weight, g). Kernel yield and stover yield were measured plot-wise and converted to kg ha^{-1}. Harvest index (HI) was computed as kernel yield divided by total biological yield.

Nutrient uptake. Plant samples were digested in a di-acid mixture (HNO_3:$HClO_4$ = 9:4). Nitrogen content was determined by the micro-Kjeldahl method (Jackson, 1973); phosphorus by the vanadomolybdophosphoric acid colorimetric method at 660 nm; potassium by flame photometry. Nutrient uptake (kg ha^{-1}) was calculated as (nutrient content % × yield kg ha^{-1}) / 100.

Phytotoxicity. Phytotoxic symptoms (leaf injury, wilting, vein clearing, necrosis, chlorosis, stunting, epinasty, and hyponasty) were scored on a 0–10 scale at 3, 7, 10, and 14 days after each application (0 = no injury, 10 = 91–100% injury).

2.5 Statistical analysis

All data were subjected to Analysis of Variance (ANOVA) for RCBD using standard procedures (Cochran and Cox, 1957). Treatment differences were evaluated at $P \leq 0.05$ using the F-ratio test. Standard error of mean (S.Em±) and critical difference (CD at 5%) were computed for each trait. Data requiring angular transformation (percentages) were transformed prior to analysis; untransformed means are presented in all tables. Statistical analyses were performed using GenStat software (VSN International, UK). All figures were prepared using Python 3.11 (matplotlib v3.8).

3 Results

3.1 Growth Parameters

3.1.1 Plant Height.

Treatment had no significant effect on plant height at 30 DAS (pre-application baseline; Table 1), confirming homogeneous initial stand. After the commencement of foliar sprays, plant height diverged significantly among treatments at 45, 60, 75, and 90 DAS. The highest-dose treatment, T5 (5 ml L^{-1}), produced the tallest plants at all post-application stages (83.14, 151.46, 234.76, and 265.28 cm at 45, 60, 75, and 90 DAS, respectively) and exceeded the untreated control (T1: 68.08, 125.33, 194.27, and 219.52 cm) by 22.1%, 20.9%, 20.8%, and 20.8%, respectively. T5 was statistically at par with T4 (3 ml L^{-1}) and T3 (2.5 ml L^{-1}) throughout (Figure 1). These results indicate that Gehna Super exerts a dose-dependent promotive effect on internode elongation and overall shoot extension, consistent with the role of cytokinin-like and auxin-potentiating compounds frequently reported in seaweed-based bio-stimulants (Battacharyya *et al.*, 2015).

Table 1. Effect of foliar spray of Gehna Super on plant height (cm) of maize at different growth stages

Treatment	**30 DAS**	**45 DAS**	**60 DAS**	**75 DAS**	**90 DAS**
T1: Untreated control	23.60	68.08	125.33	194.27	219.52
T2: Gehna Super @ 2 ml L^{-1}	22.00	73.78	136.84	212.10	239.68
T3: Gehna Super @ 2.5 ml L^{-1}	24.35	77.54	139.33	215.96	244.03
T4: Gehna Super @ 3 ml L^{-1}	20.15	80.15	146.79	227.53	257.11
T5: Gehna Super @ 5 ml L^{-1}	22.40	83.14	151.46	234.76	265.28
S.Em±	0.91	2.04	4.49	6.72	7.55
CD @ 5%	NS	6.29	13.82	20.70	23.26

NS = Non-significant; DAS = Days after sowing. Values are means of four replications. CD values at $P \leq 0.05$.

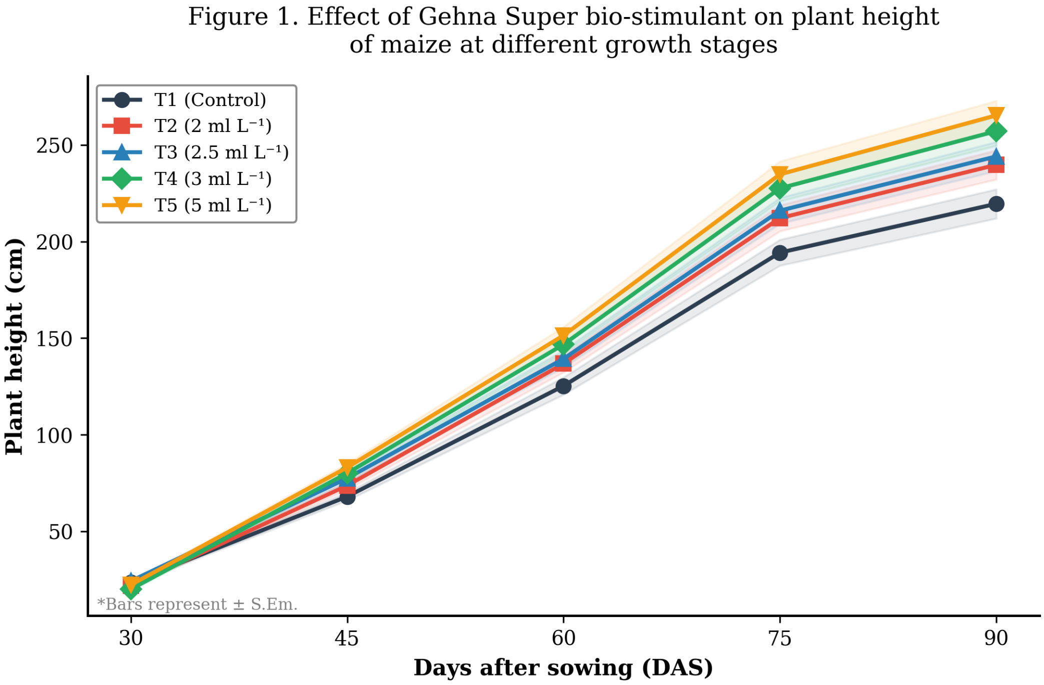

Figure 1. Effect of Gehna Super bio-stimulant on plant height of maize at different growth stages. Lines represent treatment means; shaded bands indicate ± S.Em.

3.1.2 Number of Leaves per Plant. The number of leaves per plant did not differ significantly among treatments at 30 DAS. Significant differences emerged at 45 DAS and persisted through 90 DAS. T5 recorded the highest leaf number at 90 DAS (15.58 leaves $plant^{-1}$), exceeding T1 (13.75) by 13.3% and exceeding the CD value (1.25). T4 (14.60) and T3 (14.18) were intermediate and significantly superior to T1. Increased leaf number reflects enhanced meristematic activity and accelerated phyllochron development, likely mediated by cytokinin-type signals present in the bio-stimulant formulation.

3.1.3 Leaf area per Plant and Leaf area Index. Leaf area per plant was not significantly different at 30 DAS but diverged significantly from 45 DAS onwards. At 90 DAS, T5 attained the largest leaf area per plant (6,996.00 cm^2 $plant^{-1}$) compared to T1 (6,119.50 cm^2 $plant^{-1}$), representing a 14.3% increase. T4 (6,743.25 cm^2) and T3 (6,561.25 cm^2) were statistically on par with T5. Correspondingly, LAI at 90 DAS was highest in T5 (3.89) versus T1 (3.40), with T4 (3.75) and T3 (3.65) being at par (Figure 2). An LAI in the range of 3.5–4.0 is considered near-optimal for light interception in maize (Maddonni and Otegui, 1996), indicating that T3–T5 achieved a near-optimum canopy architecture.

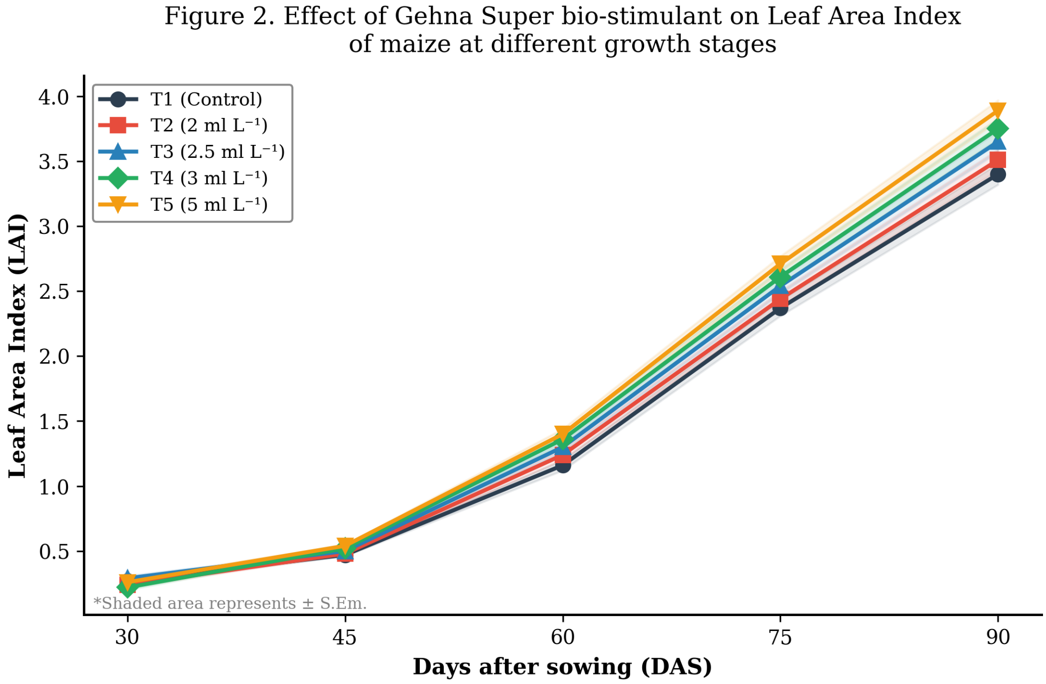

Figure 2. Effect of Gehna Super bio-stimulant on Leaf Area Index (LAI) of maize at different growth stages. Shaded bands indicate ± S.Em.

3.1.4 Dry Matter Accumulation. Total dry matter (TDM) did not differ significantly at 30 DAS among treatments. Following bio-stimulant application, TDM increased significantly across all growth stages. At harvest, TDM was highest in T5 (463.16 g plant^{-1}), followed by T4 (433.77 g), T3 (400.05 g), T2 (409.52 g), and T1 (367.60 g; Figure 3). The increments over control were 25.6% (T5) and 18.0% (T4), reflecting the bio-stimulant's capacity to sustain source activity through the grain-filling phase. Component analysis revealed that cob dry matter exhibited the most pronounced response: T5 recorded 286.60 g cob dry matter plant^{-1} at harvest versus 220.10 g in T1 (+30.2%), indicating preferential enhancement of assimilate partitioning to reproductive organs.

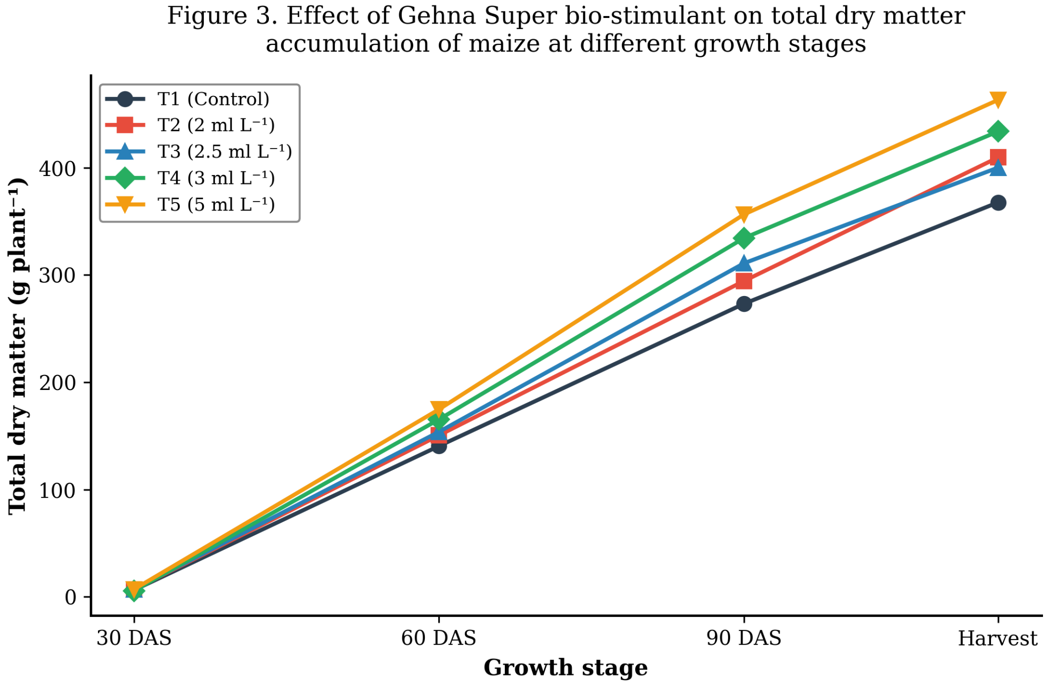

Figure 3. Effect of Gehna Super bio-stimulant on total dry matter accumulation (g plant^{-1}) of maize at different growth stages

3.2 Yield Attributes

Yield-attributing traits were significantly influenced by treatments, except number of cobs per plant (Table 2). The highest-performing treatment, T5, recorded the greatest values for all significant yield components: cob length 22.93 cm (+25.8% over T1), cob girth 19.93 cm (+13.7%), rows per cob 15.80 (+18.8%), kernels per row 36.90 (+26.4%), kernels per cob 582.59 (+50.2%), kernel weight per cob 255.23 g (+21.0%), and test weight 30.60 g (+8.1%; Figure 6). T4 (3 ml L^{-1}) and T5 were statistically at par for most attributes, while T3 was intermediate. The marked increase in kernels per cob is agronomically noteworthy as it is a composite function of rows per cob and kernels per row, both of which are strongly sink-determined traits positively regulated by assimilate supply and pollination efficiency.

Table 2. Effect of foliar spray of Gehna Super on yield attributes of maize at harvest

Treatment	Cobs plant^{-1}	Cob length (cm)	Cob girth (cm)	Rows cob^{-1}	Kernels row^{-1}	Kernels cob^{-1}	Kernel wt./cob (g)	Test wt. (g)
T1: Control	0.95	18.23	17.53	13.30	29.20	387.89	210.93	28.30
T2: 2 ml L^{-1}	1.00	19.40	17.60	13.53	30.93	418.11	222.25	28.53
T3: 2.5 ml L^{-1}	1.00	20.45	18.05	14.00	33.20	465.50	233.33	29.85
T4: 3 ml L^{-1}	1.13	21.60	18.40	14.93	35.03	523.40	245.05	29.93
T5: 5 ml L^{-1}	1.23	22.93	19.93	15.80	36.90	582.59	255.23	30.60
S.Em±	0.10	0.89	0.54	0.58	1.23	25.81	7.84	0.25
CD @ 5%	NS	2.73	1.65	1.77	3.78	79.52	24.17	0.78

NS = Non-significant. Values are means of four replications. CD at $P \leq 0.05$.

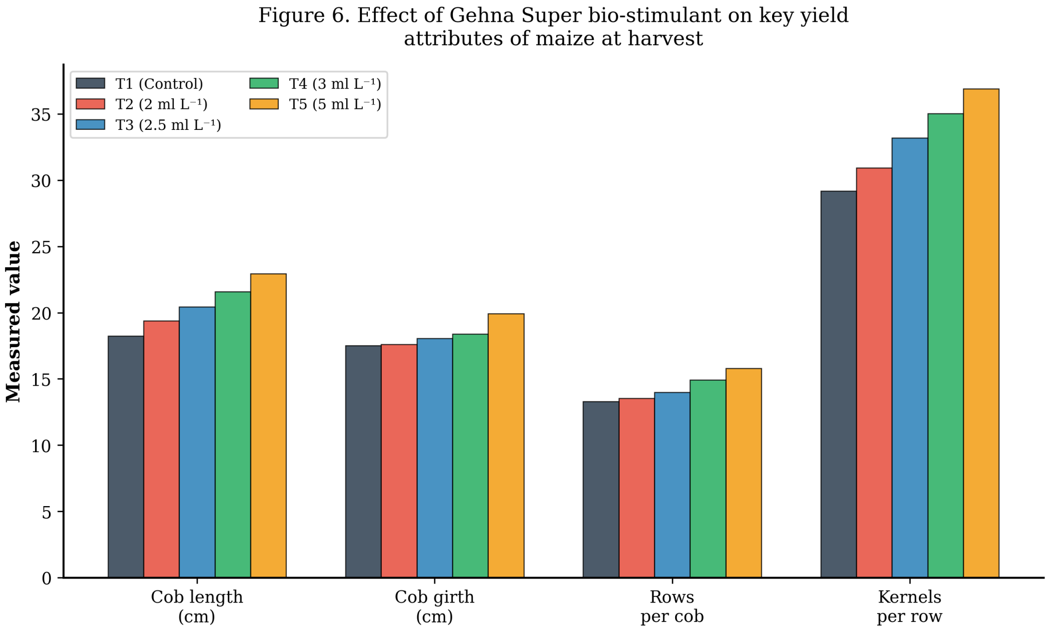

Figure 6. Effect of Gehna Super bio-stimulant on key yield attributes (cob length, cob girth, rows per cob, kernels per row) of maize at harvest.

3.3 Kernel Yield, Stover Yield, and Harvest Index

Kernel yield and stover yield differed significantly among treatments, whereas harvest index (HI) showed no significant treatment effect (Table 3). T5 produced the highest kernel yield (8,369 kg ha^{-1}), exceeding T1 (6,113 kg ha^{-1}) by 36.9%, T4 by 5.6%, and T3 by 9.9%. T4 and T3 were statistically on par with T5 (CD = 781 kg ha^{-1}). Stover yield followed a similar trend, with T5 recording 8,333 kg ha^{-1} vs. 6,892 kg ha^{-1} in T1 (+20.9%). The marginal and non-significant HI differences (0.470 to 0.501) suggest that bio-stimulant application improved overall crop productivity proportionally rather than altering the fundamental assimilate partitioning ratio (Figure 4).

Table 3. Effect of foliar spray of Gehna Super on kernel yield, stover yield, and harvest index of maize

Treatment	Kernel yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index	Yield gain over T1
T1: Untreated control	6113.25	6891.75	0.470	—
T2: Gehna Super @ 2 ml L^{-1}	7348.50	7561.00	0.492	+20.2%
T3: Gehna Super @ 2.5 ml L^{-1}	7613.00	7800.50	0.494	+24.5%
T4: Gehna Super @ 3 ml L^{-1}	7923.75	8052.25	0.496	+29.6%
T5: Gehna Super @ 5 ml L^{-1}	8369.00	8333.00	0.501	+36.9%
S.Em±	253.52	209.69	0.011	—
CD @ 5%	781.17	646.11	NS	—

NS = Non-significant. Values are means of four replications. CD at $P \leq 0.05$. Yield gain (%) calculated relative to T1.

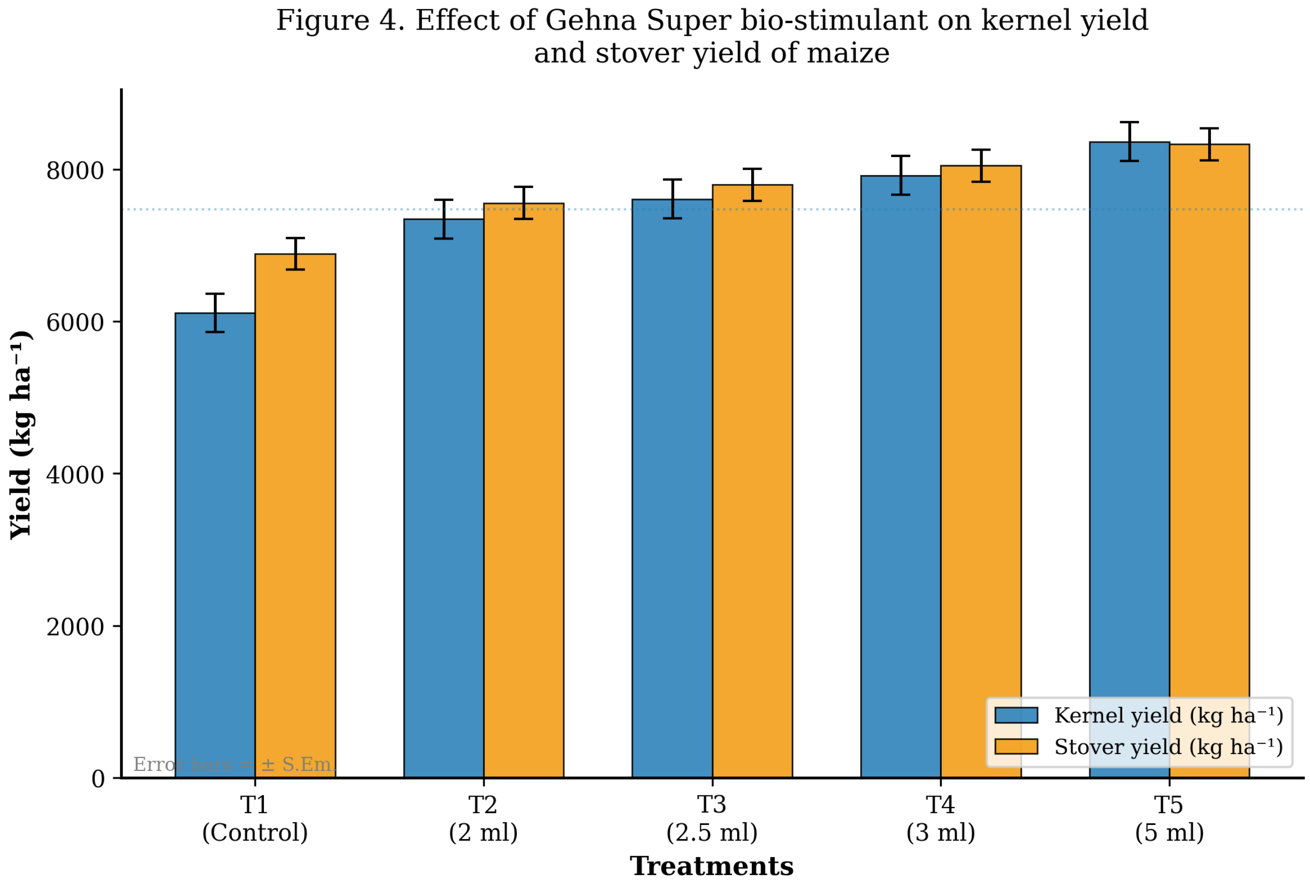

Figure 4. Effect of Gehna Super bio-stimulant on kernel yield and stover yield (kg ha^{-1}) of maize. Error bars represent ± S.Em.

3.4 Nutrient Uptake

All three nutrients (N, P, K) showed significant treatment effects (Table 4; Figure 5). T5 recorded the highest N uptake (273.93 kg ha^{-1}), exceeding T1 (254.08 kg ha^{-1}) by 7.8%, while T4 (265.50 kg ha^{-1}) was statistically at par. Phosphorus uptake in T5 (50.98 kg ha^{-1}) exceeded T1 (45.48 kg ha^{-1}) by 12.1%. Potassium uptake in T5 (191.65 kg ha^{-1}) was 6.8% higher than T1 (179.48 kg ha^{-1}). The incremental improvements in nutrient uptake under Gehna Super treatments are attributable to expanded root systems and increased leaf area enabling greater photosynthetic carbon fixation, which in turn drives greater mineral absorption through mass flow and diffusion. The relatively modest percentage gains in nutrient uptake relative to the large percentage gains in yield suggest that bio-stimulant application improved nutrient use efficiency (NUE) — a highly desirable trait for sustainable intensification.

Table 4. Effect of foliar spray of Gehna Super on N, P, and K uptake (kg ha^{-1}) by maize

Treatment	**N uptake (kg ha^{-1})**	**P uptake (kg ha^{-1})**	**K uptake (kg ha^{-1})**
T1: Untreated control	254.08	45.48	179.48
T2: Gehna Super @ 2 ml L^{-1}	256.20	46.13	181.63
T3: Gehna Super @ 2.5 ml L^{-1}	258.13	47.68	183.18
T4: Gehna Super @ 3 ml L^{-1}	265.50	49.30	187.33
T5: Gehna Super @ 5 ml L^{-1}	273.93	50.98	191.65
S.Em±	4.44	1.16	2.69
CD @ 5%	13.69	3.59	8.28

Values are means of four replications. CD at $P \leq 0.05$.

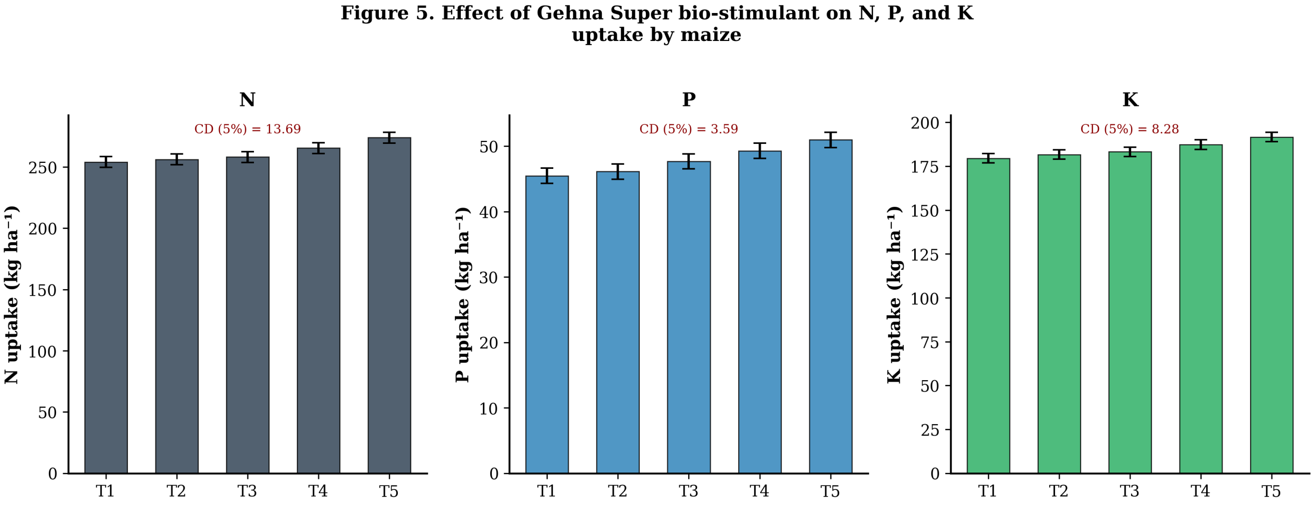

Figure 5. Effect of Gehna Super bio-stimulant on nitrogen (N), phosphorus (P), and potassium (K) uptake (kg ha^{-1}) by maize. Error bars represent ± S.Em.

3.5 Phytotoxicity assessment

No phytotoxic symptoms — including leaf injury, wilting, vein clearing, necrosis, chlorosis, stunting, epinasty, or hyponasty — were observed at any application dose at any observation date (3, 7, 10, and 14 days after each spray). Phytotoxicity scores uniformly remained at zero (0 on the 0–10 scale) across all treatments, confirming the safety of Gehna Super for foliar application on maize up to 5 ml L^{-1}.

3.6 Cost–Benefit analysis

Cost–benefit analysis revealed that all Gehna Super treatments were economically profitable relative to no treatment (Table 5; Figure 7). T4 (3 ml L^{-1}) achieved the most favorable C:B ratio of 1:3.42, generating a net profit of ₹29,421 ha^{-1} from an investment of ₹8,600 ha^{-1}. T3 (2.5 ml L^{-1}) and T5 (5 ml L^{-1}) yielded C:B ratios of 1:3.09 and 1:2.88, respectively. While T5 generated the highest absolute net profit (₹35,171 ha^{-1}), the disproportionately higher product cost at 5 ml L^{-1} reduced its C:B ratio below that of T4. These findings underscore the economic advantage of using intermediate bio-stimulant doses for commercial maize production.

Table 5. Cost–benefit analysis of Gehna Super application on maize

Treatment	**Market price (₹ L^{-1})**	**App. cost (₹ ha^{-1})**	**Kernel yield (kg ha^{-1})**	**Add. yield (kg ha^{-1})**	**Gross profit (₹ ha^{-1})**	**Net profit (₹ ha^{-1})**	**C:B ratio**
T1: Control	—	—	6113.25	—	—	—	—
T2: 2 ml L^{-1}	₹900	6800	7348.50	1235.25	25940	19140	1:2.81
T3: 2.5 ml L^{-1}	₹900	7700	7613.00	1499.75	31495	23795	1:3.09
T4: 3 ml L^{-1}	₹900	8600	7923.75	1810.50	38021	29421	1:3.42
T5: 5 ml L^{-1}	₹900	12200	8369.00	2255.75	47371	35171	1:2.88

Application charges: 3,200 ha^{-1}; Market price of produce: 2,100 per quintal.

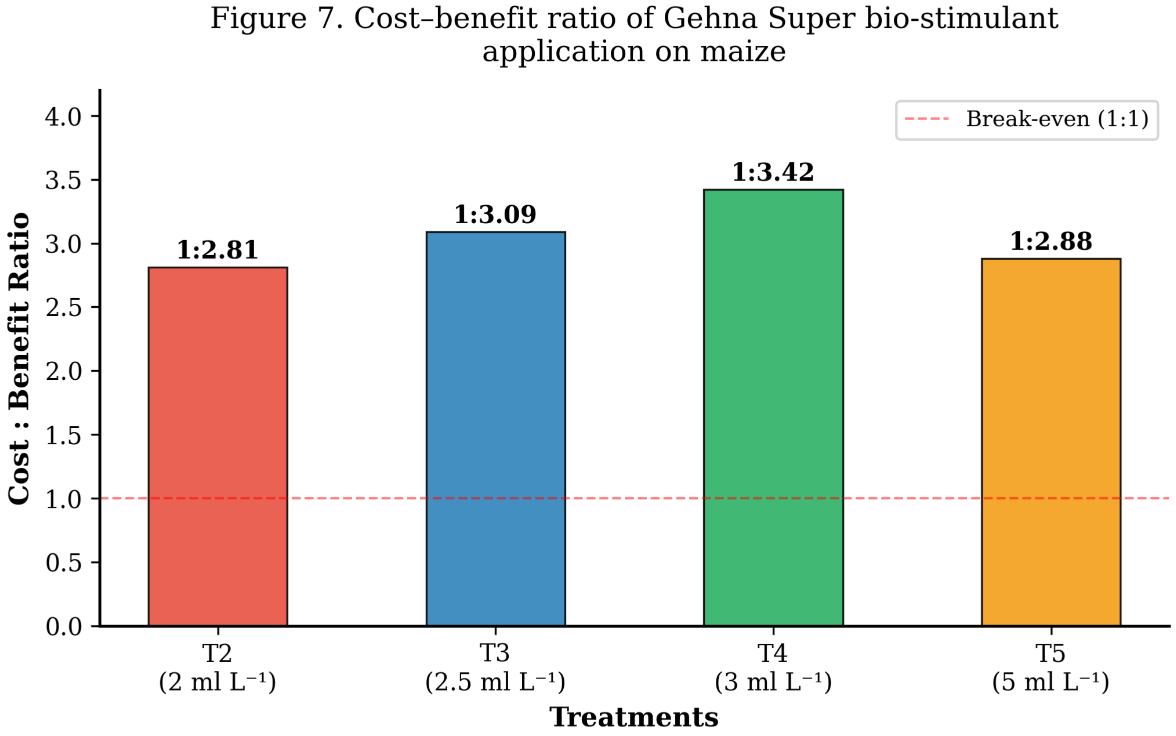

Figure 7. Cost–benefit ratio of Gehna Super bio-stimulant at different concentrations for maize production.

4 Discussion

The present study demonstrates a consistent, dose-dependent improvement in maize growth and productivity in response to foliar application of Gehna Super bio-stimulant. The progressive enhancement in plant height, LAI, dry matter accumulation, yield attributes, and kernel yield from T1 through T5 follows a classical dose–response pattern that is characteristic of bio-stimulant products containing bioactive molecules such as amino acids, trace elements, plant growth regulators, or polysaccharides. Although the precise composition of Gehna Super was not disclosed in this study, its agronomic effects align with those of protein hydrolysate- and seaweed-based bio-stimulants documented in the literature (Yakhin *et al.*, 2017; Rouphael and Colla, 2020).

The significant increases in plant height under bio-stimulant treatments are consistent with findings of Khan *et al.* (2020), who reported 15–25% height improvements in maize following seaweed extract application. The enhancement of LAI — a pivotal determinant of crop radiation interception and, consequently, dry matter production — is particularly significant. A higher LAI translates directly into greater canopy photosynthesis. The near-optimal LAI values (3.65–3.89) recorded in T3–T5 at 90 DAS are expected to support high biomass productivity, as confirmed by the TDM data.

The 50.2% increase in kernels per cob in T5 relative to T1 merits attention. Kernels per cob in maize is primarily determined during the period around silking when competition between ear growth and vegetative organs for assimilates is intense. Bio-stimulants have been shown to reduce this competition by enhancing phloem loading efficiency and ear sink strength (Ruzicka *et al.*, 2010). The concurrent improvements in cob length and girth further confirm that Gehna Super promotes ear development both in the linear (rachis elongation) and radial (cob filling) dimensions.

The modest but statistically significant improvements in N, P, and K uptake — combined with substantially larger yield gains — suggest improved NUE. This is consistent with the hypothesis that bio-stimulants activate root enzymatic processes (e.g., nitrate reductase, acid phosphatase) that improve ion acquisition per unit root biomass (Ruzicka *et al.*, 2010; Bulgari *et al.*, 2015). Under the low-to-medium fertility conditions of this Alfisol, even marginal improvements in NUE could translate into economically meaningful yield gains — a particularly valuable property for smallholder farming systems.

The C:B ratio analysis provides crucial practical guidance. The highest productivity (T5) does not translate into the best economic outcome because product cost scales with dose. The optimal economic dose of 3 ml L^{-1} (T4) maximizes the C:B ratio at 1:3.42, meaning that every rupee invested in bio-stimulant application generates ₹3.42 in returns. This finding is directly actionable for extension advisory and farmer decision-making.

The complete absence of phytotoxicity across all doses and all observation points is an important safety confirmation for product registration and commercial use. This is consistent with the regulatory classification of bio-stimulants as low-risk inputs compared to conventional pesticides or high-nitrogen fertilizers.

5 Conclusion

This study provides the first replicated, multi-dose field evidence for the agronomic efficacy of Gehna Super bio-stimulant in maize under South Indian Eastern Dry Zone conditions. Foliar application significantly enhanced vegetative growth (plant height, leaf area index, dry matter accumulation), yield attributes (cob dimensions, kernel number), and kernel yield (up to 36.9% over untreated control at 5 ml L^{-1}). Nutrient uptake was improved, indicating enhanced nutrient use efficiency. Gehna Super was phytotoxically safe at all tested concentrations. The dose of 3 ml L^{-1} applied four times (at 30, 45, 60, and 75 DAS) is recommended as the optimal agronomic and economic rate, yielding a C:B ratio of 1:3.42. Future research should investigate the molecular basis of Gehna Super's mode of action, its performance across maize hybrids and irrigation levels, and its integration with precision nutrient management for further productivity gains.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the technical staff of the AICRP on Sunflower, ZARS, GKVK, UAS Bangalore for field assistance, and the Soil Science laboratory for nutrient analysis support.

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