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Increase in above ground dry matter accumulation with application microbial consortia and zinc fertilization in different cultivation methods of wheat

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Abstract
The field experiment was conducted to study the effect of different methods of wheat cultivation, microbial consortia application and zinc (Zn) (0 and 5 kg Zn ha^{-1} soil applied through zinc sulphate heptahydrate) fertilization on the growth attributes of wheat. The experiment was conducted in split plot design and replication thrice with wheat variety HD-2967. The results showed that, application of RDN (120 kg N/ha and 25.8 kg P/ha) + Zn recorded highest value for all the dry matter accumulation, leaf area index (LAI) and crop growth rate (CGR) studied which remain on par with application of 75% RDN + *Anabaena sp.* (CR1) + *Providencia* sp. (PR3) consortia + Zn and 75% RDN + *Anabaena-Pseudomonas* biofilmed formulations + Zn. The increase in dry matter production due to microbial inoculation was 11.1-12.0 and 35.2-44.7 g/m2 at 60 and 90 DAS, respectively; while Zn fertilization increases dry matter production by 9.8-11.6 g/m2 and 18.2-20.0 g/m2 at 60 and 90 DAS, respectively. The zero tillage wheat was significantly superior in LAI and CGR over conventional drill sown wheat and system of wheat intensification.

Keywords: Microbial consortia; crop growth rate; zero tillage wheat; zinc fertilization

Introduction

Wheat is second largest grown arable crop accounting 30.65% and 23.37% area out of total area occupied by cereals and food-grains in India, respectively with respective share of 37.08 and 33.82% to total cereal and food-grain production in India, respectively. Wheat have significant share in input used such as account 23.9% out of the gross cropped area under foodgrain crops, 34.3% out of total foodgrain production, 24% nitrogen and 24% phosphorus fertilizer out of total fertilizer used in India and significant amount of herbicide use in India. Wheat is grown on 31.2 million ha area with production and productivity of 112.9 million tonnes and 3615 kg/ha, respectively in India. Wheat is known crop for early adopter of higher yielding varieties (wheat revolution or else called as green revolution) as well as conservation agriculture (zero tillage) based practices in India. The crop is known and produced for its diversified products as well as superior backing qualities over coarse cereals. Considering its significant importance in food and feed supplying capacity and adoption to energy efficient practices, wheat is considered as important crop for agronomic modulation study. The tillage systems, cultivation methods, land configuration study, varietal and species evaluation for quality and yield attributes, precision agricultural practices, rhizosphere exploration of desirable microorganisms, zinc and iron bio-fortification through agronomic and microbes mediated ways, new low dose herbicide, herbicide resistance and shift in weed flora are the major themes of research in wheat at present.

Significant changes in tillage system occur in wheat cultivation in Indo-Gangetic plains in rice-wheat cropping system through zero tillage and minimum tillage system and different land configuration such as furrow irrigated raised bed (FIRB) and permanent beds. The changes in tillage system are worthy on account of its cost and energy saving nature as well and insuring timeliness in sowing. The potential benefits of zero tillage system were reported (Somasundaram *et al.*, 2020) [9] widely; while difficult in seed and sowing, fertilization and extensive use of herbicide are reported as bottleneck in its adoption (Lal *et al.*, 2022) [4].

Being untilled field, the organic matter in the form of stubbles of previous crop and different physical properties, the soil micro-climate is expected to be different leading to changes in soil microflora (Bhatt, 2017; Singh *et al*., 2014) [1, 7]. These variations in soil micro-climate needs to explore for effectiveness of use of microbial inoculations and their contribution of plant growth. Saurabh *et al*. (2021) [6] reported that macro aggregate stability, soil organic carbon, microbial biomass carbon, flourescein diacetate and dehydrogenase activity in zero tilled direct seeded rice followed by zero till wheat were higher by 47, 18, 56, 48 and 53%, respectively over other crop establishment methods in rice-wheat cropping system indicating the positive effect of zero tillage on different soil properties.

Besides zero tillage, system of crop intensification principles applied to wheat (system of wheat intensification) (SWI) (Dass *et al*., 2023; Singh *et al*., 2024) [2, 8] also create the variation in soil biological properties leading to creation of scope for investigation of performance of different microbial consortia and their effect on crop growth. The SWI was reported to have variation in sources of crop nutrition, seed and sowing specifications and inter-cultivations practices. These variations reflected in to variation in the yield of crop in SWI. The microbial inoculation performance is affected significantly due to changes in soil physical, chemical and biological properties; therefore evaluation of potential variation in performance of microbial consortia across different cultivation methods with same level of input and management practices will be worthy. The contribution of cultivation methods and microbial consortia were mostly evaluated and expressed on yield and crop nutrition; while their progressive contribution over the different growth stages is least highlighted. Hence attempt has been made to study the combination of microbial inoculation with chemical fertilizers in different methods of wheat cultivation for their effect on growth attributes of wheat across the different growth stages.

Materials and Methods

The field experiment was conducted during *Rabi*-season of 2013-14 and 2014-15 consecutively for two year at Research Farm of ICAR-Indian Agricultural Research Institute, New Delhi, India located at $28^0$38' N, $77^0$10' E and 228.6 m above the mean sea-level. The objective was to study the effect of nutrient management treatments on aboveground dry matter production, leaf area and other secondary growth attributed calculated based on the dry matter accumulation across the crop growth duration in three different methods of wheat cultivation. The climate of New Delhi is of subtropical and semi-arid type with hot and dry summer and cold winter. The mean annual rainfall and evaporation were 605 mm and 850 mm, respectively. The rainfall during year for experimentation was 147.6 and 308.6 mm in 2013-14 and 2014-15, respectively; while evaporation during same period was 542.5 mm and 580.5 mm, respectively. The soil were analyzed before start of experiment with available N, available P and available K and DTPA-extractable Zn content of 200.3 kg/ha, 23.3 kg/ha, 284.6 kg/ha and 0.87 mg/kg, respectively. The soil pH and soil organic carbon content was 7.6 and 0.54% respectively.

The experiment was planned in split plot design involving three wheat cultivation methods (Conventional drill-sown wheat (DSW), System of wheat Intensification (SWI) and zero-tillage wheat (ZTW)) as main plot (42.3 m × 1.8 m = 76.14 m^2) and nine subplot (4.7 m × 1.8 m = 8.46 m^2) treatments. The sub plot treatment consists of different rate and sources of N and P application and rates of Zn fertilization. The wheat (*HD-2967*) was grown in three cultivation methods with sowing on the same data in all three cultivation methods (15-17 November and 17-20 November, respectively in 2013-14 and 2014-15). For field preparation, one ploughing with disc plough followed by disc harrowing and planking once is done for CDW and SWI; while for ZTW sowing is done without any field preparation (only reshaping of bunds were done). For sowing wheat in CDW, 100 kg seed per hectare was at 22.5 cm row to row spacing in solid lines; while for ZTW, 120 kg seeds were sowing per hectare at 20 cm row spacing. In SWI, dibbling of 1-2 seeds at 20 cm × 20 cm spacing was done.

The rates of N application were 0, 90 and 120 kg N/ha; while for P, it was 0, 19.35 and 25.80 kg P/ha. The sources of N and P were chemical fertilizers (urea and single super phosphate) and microbial consortia (MC) (MC1: (*Anabaena* sp. (CR1) + *Providencia* sp. (PR3) consortia; MC2: *Anabaena-Pseudomonas* biofilmed formulations). The Zn was applied at two rates (0 and 5 kg Zn/ha) through zinc sulphate heptahydrate at the time of sowing. The potassium was uniformly applied in all plots @ 49.8 kg/ha at the time of sowing. The nitrogen was applied in three equal split (at sowing, 30 and 60 DAS) in all the cultivation methods; while entire quantity of P was applied at sowing as per the treatment details (Table 1). All treatments were replicated thrice. For seed treatment with microbial consortia, presoaked seeds were treated with thick slurry of microbial cultures, using 1% carboxylmethyl cellulose (CMC) as a sticker and kept for shade drying. The microbial consortia were prepared by mixing with vermiculite (hydrous phyllosilicate mineral): compost (1:1) as the carrier. The paddy straw compost was C/N 16.22 and humus 13.8% (pH 7.34), and the cyanobacterial, fungal, and bacterial colony forming units in the formulations were 10^4, 10^5, and 10^8 g^{-1} carrier, respectively, as optimized in earlier studies (Prasanna *et al*., 2015). All the bacterial/cyanobacterial strains were maintained in the culture collection of the Division of Microbiology, ICAR—Indian Agricultural Research Institute, New Delhi, India. For weed management, hand weeding was done twice (20 and 40 DAS) in all cultivation methods. For water management, four irrigations were applied in 2013-14 and six irrigations were applied in 2014-15, respectively in all cultivation methods. The critical growth stage approach was followed for irrigation in all three cultivation methods.

The above ground dry matter accumulation was measured at 30, 60 and 90 days after sowing (DAS) in all cultivation methods. For above ground dry matter accumulation measurement 0.5 m row length at three different places in each plot was taken in CDW and SWI; while for SWI, three hills from each plot were taken. For measurement of Leaf area same plant selected for dry matter measurement was used first and then used for measurement of dry matter accumulation. For measurement for leaf area Index, Leaf area meter (LI-COR model L1-3000, Lambda Instrument Corporation, Nebraska, USA) was used. For measurement of dry mater accumulation, plant samples were air dried and further over dried at 60±2 °C still a constant was achieved. For calculation for crop growth rate (CGR), relative growth rate (RGR) and leaf area index (LAI) following formulas were used:

$$\text{Crop growth rate (CGR)} = \frac{W2\text{-}W1}{t2\text{-}t1}$$

$$\text{Relative growth rate (RGR)} = \frac{\text{Log } W2\text{-Log } W1}{t2\text{-}t1}$$

$$\text{Leaf Area Index (LAI)} = \frac{\text{Leaf area (cm2)}}{\text{Growing area (cm2)}}$$

Where, W1 and W2 indicated the weight of over dry matter recorded at two different times at t1 and t2, respectively.
The data was statically analyzed by using F-test as per standard statistical procedure (Gomez and Gomez, 1984) and least significant difference (LSD) values (P = 0.05) were used to determine the significance of difference between treatment means.

Results and Discussion

The above ground dry matter production is significantly affected by cultivation methods and nutrient management treatment at all observations (30, 60 and 90 DAS) with positive interaction effect (Table 1). Among the crop establishment methods, ZTW had significantly higher dry matter production over other CMs at all observations with increase in 4-5-5.1 and 13.4-15.5 g/m2 Over CDW at 60 and 90 DAS and 4.6-5.2 and 13.4-15.5 g/m2 over SWI at 60 and 90 DAS, respectively. The residual soil fertility after direct seeded rice, better crop establishment and growth and optimum plant population are observed in ZTW and these the reasons for superiority in dry matter production. The significance of ZTW in growth and yield was also reported by Yang *et al*. (2020) [11] and Dass *et al*. (2023) [2]. The other probable reason might be 20% higher seed rate in ZTW, better soil physical condition due to aerobic rice in previous season, higher microbial activities due to retention of organic matter in the form of stubbles of previous season rice and better performance of microbial inoculants in ZTW. Application of RDN + Zn recorded highest dry matter production at all observation indicating the significance of optimal fertilization and responsiveness of wheat to optimal fertilization in all three CMs. The dry matter production in two treatments involving application of 75% RDN + MC1 or MC2+ Zn remain on par with the RDN + Zn indicating the contribution of microbial inoculation. The significance of Zn fertilization was not occurred at 30 DAS; while at 60 and 90 DAS, zing fertilization significantly increase the dry matter production. The increase in dry matter production due to microbial inoculation was 11.1-12.0 and 35.2-44.7 g/m^2 at 60 and 90 DAS, respectively; while Zn fertilization increases dry matter production by 9.8-11.6 g/m^2 and 18.2-20.0 g/m2 at 60 and 90 DAS, respectively. The increase in dry matter production due to application of microbial inoculations was reported in Thakur and Agrawal (2020) [10].
The LAI varies from 1.36 to 1.78 at 60 DAS and 3.36 and 4.16 at 90 DAS with highest value in ZTW and RDN + Zn (Table 2). The non-significance of CMs and nutrient management treatment at 30 DAS indicate the less share of leaf area in total dry matter production. The significant response of LAI to microbial inoculations and zinc fertilization indicates the role of both in chlorophyll production and ultimately imparting the nitrogen nutrition to wheat in our study. The LAI values in RDN+Zn and 75% RDN + MC1 or MC2+ Zn remain on par both at 60 and 90 DAS. The optimal and sub-optimal fertilization (75% RDN) had shown significant fertilization indicating the impact of optimal fertilization in plant growth besides the grain yield are reported and studied widely. The ZTW had significantly higher LAI indicting better crop nutrition over CDW and SWI which might be due to better soil physical condition promoting root growth and more residual nutrients in ZTW grown after aerobic rice in our study.
This increase in dry matter production and leaf area was also reflected in CGR at 30-60 and 60-90 DAS and RGR at 30-60 DAS (Table 2 and 3). The CGR was significantly higher in ZTW at 30-60 DAS and 60-90 DAS over other CMs; while both CDW and SWI remain on par at all observations. The non-significant difference in CDW and SWI indicates, higher dry matter production per plant in SWI will be sufficient to compensate the reduced seed rate in SWI (25-30 kg/ha) over CDW (100 kg/ha). The superiority in SWI in literature might due to source and rate of nutrient application as well as seed treatment with different microbial inoculants; while in our study all practices, rate and sources of crop nutrition was same and the results in our case is truly due to changes in growth of wheat in SWI due to modification of plant and crop geometry. Among nutrient management treatments, highest CGR was recorded in RDN+Zn which is not par with 75% RDN + MC1 + Zn and 75% RDN + MC2+Zn. These three treatments had significantly higher values than same treatment without Zn application indicating the role of Zn fertilization in CGR. The impact optimal and suboptimal fertilization on dry matter accumulation was also reflected on the CGR with significant superiority of optimal fertilization (RDN) over sub-optimal fertilization (75% RDN). The interaction effect of CMs and nutrient management options was positive and more consistent at 60-90 DAS with all nutrient management options perform significantly superior in ZTW over same treatment applied in other CMs in both years. At 30-60 DAS, treatment performance across CMs differ; while their performance was not consistent during second year; while during first year 75% RDN + MC1 remain on par in all methods and other treatments were statistically superior other treatments. The value of RGR was significantly higher in ZTW at 30-60 DAS in both years; while during second year, all CMs remains on par (Table 2 and 3). The trend in RGR at 30-60 DAS was same as that CGR; while at 60-90 DAS, treatment performance are different with highest values in 75% RDN + MC2 which remain on par with 75% RDN + MC21 and RDN in first year; while during second year most of the treatments were remain on expect RDN+Zn, 75% RDN + MC1+Zn and 75% RDN + MC2+Zn (Table 3). This might be due to less contribution of dry matter for further dry matter production in treatment in which the total dry mater accumulation was significantly higher. Hence our observation is that, every unit increase in dry matter across the growth stages do not contributes equally to further dry matter production as indicated by GRG at 60-90 DAS. In nutshell our study state that there is significant contribution of microbial inoculants, zinc fertilization and optimal fertilization to studied growth parameter with highest being with optimal fertilization (Over sub-optimal fertilization) followed by microbial inoculation and least in Zn fertilization. The interaction effect was found significant which say about significant effect of tillage, seed and soil specifications in the performance of microbial consortia and fertilization.

Table 1: Effect of nutrient management options on above ground dry matter production (g/m^2) in three cultivation methods of wheat

Treatment	30 DAS		60 DAS		90 DAS	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Conventional drill-wheat (CDW)						
Control	27.79	27.3	202.9	187.9	601.5	588.3
RDN	31.14	30.3	236.5	222.8	708.1	678.3
RDN + Zn	31.31	30.5	248.2	232.7	728.3	696.7
75% RDN	30.41	29.7	222.0	208.9	658.3	638.1
75% RDN + Zn	30.62	29.9	225.8	212.5	669.2	647.8
75% RDN + MC1	31.31	30.5	235.6	221.8	706.7	679.1
75% RDN + MC1 + Zn	31.17	30.4	245.7	231.1	721.9	691.3
75% RDN + MC2	31.09	30.3	234.7	221.2	705.3	676.5
75% RDN + MC2 + Zn	31.23	30.4	246.1	231.5	724.2	692.5
Mean	30.67	29.9	233.1	219.0	691.5	665.4
System of Wheat Intensification (SWI)						
Control	27.85	27.4	203.2	188.1	602.4	589.2
RDN	31.14	30.4	236.5	222.8	708.1	678.2
RDN + Zn	31.25	30.5	247.9	232.4	727.4	695.8
75% RDN	30.68	30.0	223.2	210.0	662.2	642.0
75% RDN + Zn	30.59	29.9	225.7	212.4	668.8	647.3
75% RDN + MC1	31.06	30.3	234.5	220.7	703.1	675.6
75% RDN + MC1 + Zn	31.13	30.4	245.5	230.9	721.5	690.8
75% RDN + MC2	31.11	30.3	234.8	221.3	705.7	676.9
75% RDN + MC2 + Zn	31.17	30.4	245.8	231.2	723.3	691.6
Mean	30.67	29.9	233.0	218.9	691.4	665.3
Zero tillage Wheat (ZTW)						
Control	28.43	27.4	209.0	193.2	620.0	604.7
RDN	31.51	30.6	241.4	227.1	722.7	690.8
RDN + Zn	31.68	30.8	253.2	237.1	743.1	709.4
75% RDN	31.06	30.2	228.0	214.3	676.8	654.5
75% RDN + Zn	31.08	30.3	231.0	217.1	685.1	661.5
75% RDN + MC1	31.25	30.3	238.6	224.2	715.1	685.5
75% RDN + MC1 + Zn	31.69	30.8	251.4	236.2	738.9	706.2
75% RDN + MC2	31.49	30.6	239.7	225.7	720.4	689.5
75% RDN + MC2 + Zn	31.73	30.8	251.7	236.5	740.8	707.0
Mean	31.10	30.2	238.2	223.5	707.0	678.8
LSD(*P*=0.05)						
Cultivation methods	0.23	0.19	2.12	1.96	6.15	5.29
Nutrient management	0.31	0.26	2.71	2.52	7.87	6.83
Interaction	0.53	0.45	4.69	4.36	13.64	11.82

RDN*: Recommended dose of nutrients 120 kg N ha^{-1} and 25.8 kg P ha^{-1}; Zn**: Soil applied 5 kg Zn ha^{-1} through zinc sulphate heptahydrate; MC1: (*Anabaena sp*. (CR1) + *Providencia sp* (PR3) consortia; MC2: *Anabaena-Pseudomonas* biofilmed formulations.

Table 2. Effect of nutrient management options on leaf area index (LAI) and crop growth rate (CGR) in three cultivation methods of wheat

Treatment	Leaf area index				Crop growth rate (g m^{-2} day^{-1})	
	60 DAS		90 DAS		30-60 DAS	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Conventional drill-wheat (CDW)						
Control	1.47	1.35	3.42	3.32	5.84	5.35
RDN	1.73	1.62	4.05	3.85	6.84	6.42
RDN + Zn	1.77	1,65	4.13	3.93	7.23	6.74
75% RDN	1.61	1.50	3.85	3.69	6.39	5.98
75% RDN + Zn	1.64	1.53	3.91	3.74	6.51	6.09
75% RDN + MC1	1.72	1.61	4.04	3.86	6.81	6.38
75% RDN + MC1 + Zn	1.75	1.63	4.09	3.90	7.15	6.69
75% RDN + MC2	1.72	1.60	4.03	3.84	6.79	6.37
75% RDN + MC2 + Zn	1.76	1.64	4.11	3.91	7.16	6.70
Mean	1.69	1.57	3.96	3.78	6.75	6.30
System of wheat intensification (SWI)						
Control	1.43	1.35	3.42	3.33	5.85	5.36
RDN	1.73	1.62	4.05	3.85	6.84	6.41
RDN + Zn	1.77	1.64	4.13	3.92	7.22	6.73
75% RDN	1.62	1.51	3.85	3.71	6.42	6.00
75% RDN + Zn	1.64	1.52	3.91	3.74	6.50	6.08
75% RDN + MC1	1.72	1.60	4.02	3.84	6.78	6.35
75% RDN + MC1 + Zn	1.75	1.63	4.09	3.90	7.15	6.68
75% RDN + MC2	1.72	1.60	4.03	3.85	6.79	6.37
75% RDN + MC2 + Zn	1,76	1.64	4.10	3.90	7.15	6.69
Mean	1.69	1.57	3.96	3.78	6.74	6.30
Zero tillage wheat (ZTW)						
Control	1.51	1.39	3.52	3.42	6.02	5.53
RDN	1.77	1.65	4.13	3.93	7.00	6.55
RDN + Zn	1.81	1.68	4.21	4.00	7.38	6.88
75% RDN	1.65	1.54	3.85	3.78	6.57	6.13
75% RDN + Zn	1.67	1.56	3.91	3.82	6.66	6.23
75% RDN + MC1	1.75	1.63	4.09	3.90	6.91	6.46
75% RDN + MC1 + Zn	1.80	1.67	4.19	3.98	7.32	6.85
75% RDN + MC2	1.75	1.64	4.12	3.92	6.94	6.50
75% RDN + MC2 + Zn	1.80	1.67	4.20	3.99	7.33	6.86
Mean	1.72	1.60	4.02	3.86	6.90	6.44
LSD(P=0.05)						
Cultivation methods	0.015	0.014	0.031	0.03	0.06	0.06
Nutrient management	0.020	0.018	0.045	0.04	0.08	0.08
Interaction	0.034	0.031	0.078	0.07	0.14	0.14

Table 3: Effect of nutrient management options on crop growth rate (CGR) and relative growth rate in three cultivation methods of wheat

Treatment	Crop growth rate (g m^{-2} day^{-1})		Relative growth rate (mg g^{-1} day^{-1})			
	60-90 DAS		30-60 DAS		60-90 DAS	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Conventional drill-wheat (CDW)						
Control	13.29	13.35	66.25	64.29	36.22	38.06
RDN	15.72	15.18	67.58	66.48	36.56	37.10
RDN + Zn	16.00	15.47	69.00	67.75	35.89	36.55
75% RDN	14.54	14.31	66.27	65.07	36.23	37.22
75% RDN + Zn	14.78	14.51	66.60	65.39	36.21	37.15
75% RDN + MC1	15.70	15.24	67.27	66.16	36.62	37.30
75% RDN + MC1 + Zn	15.88	15.34	68.82	67.65	35.93	36.53
75% RDN + MC2	15.69	15.18	67.38	66.29	36.68	37.26
75% RDN + MC2 + Zn	15.94	15.37	68.80	67.69	35.98	36.52
Mean	15.28	14.88	67.55	66.31	36.26	37.08
System of wheat intensification (SWI)						
Control	13.30	13.37	66.25	64.26	36.22	38.06
RDN	15.72	15.18	67.58	66.44	36.56	37.11
RDN + Zn	15.98	15.45	69.03	67.74	35.88	36.55
75% RDN	14.63	14.40	66.15	64.91	36.25	37.24
75% RDN + Zn	14.77	14.50	66.62	65.36	36.21	37.15
75% RDN + MC1	15.62	15.16	67.38	66.23	36.60	37.30
75% RDN + MC1 + Zn	15.86	15.33	68.84	67.63	35.93	36.53
75% RDN + MC2	15.70	15.19	67.37	66.23	36.68	37.27
75% RDN + MC2 + Zn	15.92	15.35	68.83	67.68	35.98	36.53
Mean	15.28	14.88	67.56	66.27	36.26	37.08
Zero tillage wheat (ZTW)						
Control	13.70	13.75	66.49	65.15	36.25	38.03
RDN	16.04	15.46	67.87	66.79	36.55	37.08
RDN + Zn	16.33	15.74	69.28	68.05	35.88	36.53
75% RDN	14.96	14.67	66.46	65.28	36.26	37.22
75% RDN + Zn	15.14	14.81	66.86	65.67	36.23	37.14
75% RDN + MC1	15.88	15.38	67.76	66.67	36.59	37.26
75% RDN + MC1 + Zn	16.25	15.67	69.04	67.89	35.94	36.51
75% RDN + MC2	16.02	15.46	67.67	66.59	36.67	37.23
75% RDN + MC2 + Zn	16.30	15.68	69.03	67.94	35.99	36.51
Mean	15.63	15.18	67.83	66.67	36.26	37.06
LSD (P=0.05)						
Cultivation methods	0.13	0.11	0.09	0.27	0.02	0.06
Nutrient management	0.17	0.14	0.19	0.36	0.03	0.08
Interaction	0.30	0.25	0.32	0.62	0.05	0.14

Conclusion

In conclusion, the study highlights the significant influence of crop establishment methods (ZTW) and nutrient management treatments (RDN + Zn) on dry matter production, leaf area index (LAI), and growth rates of wheat. ZTW consistently outperformed other crop establishment methods in dry matter accumulation, likely due to improved soil conditions and residual fertility. Optimal fertilization (RDN + Zn) resulted in the highest dry matter production and growth, with microbial inoculation further enhancing these effects. Zinc fertilization also contributed positively to growth, particularly at later growth stages. Overall, optimal fertilization, microbial inoculation, and zinc fertilization were key factors influencing wheat growth, with ZTW providing the best overall performance.

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