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Research article

Productivity and energy dynamics of forage oats (*Avena sativa* L.) as influenced by liquid bacterial inoculants

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Abstract

India possesses the world's largest bovine population; however, milk and meat productivity remain lower than expected. At present, the availability of both green and dry fodder is far below the existing demand, and this gap is projected to widen further, underscoring the urgent need to enhance fodder production and management strategies. In addition, efficient energy use in agriculture is the need of the hour to minimize environmental impacts. In this context, the present investigation was carried out to study the impact of liquid bacterial inoculants on productivity and energy budgeting of forage oat (*Avena sativa* L.). The field experiments were conducted at Bathinda and Ludhiana with a total of 12 treatments of liquid bacterial inoculants in a randomized complete block design (RCBD) and replicated thrice. The treatment T_{11}: RDF + *Burkholderia seminalis* + *Stenotrophomonas maltophilia*, recorded maximum growth and yield attributing traits at Bathinda and Ludhiana, respectively. Further, the correlation studies revealed a strong positive correlation between yield-attributing traits and productivity. The energy output varied from 781269.0 to 863972.0MJ/ha at Ludhiana and from 751460.5 to 851476.5 MJ/ha at Bathinda. The maximum energy output was recorded under treatment T_{11} at both Bathinda and Ludhiana. Therefore, it can be concluded that the application of liquid bacterial inoculants could play a predominant role in enhancing the productivity and energy audit (input-output relationship) of forage oats.

Keywords: Bacterial inoculants, Energetics, Forage, Oats, Yield

Introduction

India has the largest population of bovines, which includes 92 million buffaloes and 200 million cattle. Globally, this corresponds to 19.5% of the cattle population. Despite this large population of bovines, the scenario for the production of milk and meat is below the average. The supply of nutritious fodder is a prerequisite for the success of any dairy industry (Surje *et al*., 2015). However, at present, the country is experiencing a net deficit of 28.9% in concentrated feed ingredients, 23.4% in dry crop residues, and 11.24% in green fodder (Roy *et al*., 2019). Therefore, there is an urgent requirement to maximize the tonnage as well as the quality of fodder within the existing cropping systems.

Oat (*Avena sativa* L.) is a constituent of the family Gramineae (Poaceae) and commonly known as *Jai* or *Javi*. Oats are largely grown for fodder and grain purposes as they are a good source of fibres, proteins, and minerals (Chakraborty *et al*., 2014). It is widely grown during the *rabi* season in Madhya Pradesh, Uttar Pradesh, Punjab, Haryana, Himachal Pradesh, Rajasthan, Gujarat, Bihar, Andhra Pradesh and hilly areas of the southern plateau in India. It provides high-energy, nutritious, palatable fodder with good regeneration capacity and has become a promising crop of forage for livestock production (Jat *et al*., 2017).

Moreover, chemical fertilizers have been extensively used for increasing yield, but their indiscriminate use has resulted in drastic changes in the environment, such as the emission of greenhouse gases and the deterioration of soil microflora. In addition, these are expensive, depleting non-renewable resources, causing nutrient imbalances and leaching excessive polluting nutrients into the environment and are the most energy-intensive segments. The demand for energy from agriculture is increasing gradually to feed the growing world population. The optimum use of energy in agriculture not only reduces harmful effects on the environment but also moves agricultural practices towards sustainability (Dalgaard *et al*., 2001, Nasso *et al*., 2011). It is imperative to develop energy-efficient production systems that minimize energy inputs while maximizing outputs. Organic nutrient management practices represent a highly effective strategy for lowering dependence on non-renewable energy sources, thereby increasing the share of renewable energy and strengthening agricultural sustainability (Yadav *et al*., 2013). Even a modest annual improvement of 2-3% in nutrient-use efficiency can translate into substantial fertilizer savings and significant economic benefits at the national level (Sarkar *et al*., 2021). This highlights the critical role of microorganisms in maintaining agricultural productivity. Bacterial inoculants, enriched with beneficial microbes, enhance plant growth by synthesizing bioactive compounds such as phytohormones, enzymes, and vitamins, which facilitate nutrient acquisition and bolster plant defense against pathogens. Arora *et al*. (2024) evaluated the impact of liquid microbial inoculants on the productivity and energetics of forage pearl millet. It was observed that the application of liquid bacterial inoculants of *B. seminalis* + *S. maltophilia* along with the recommended dose of fertilizer (RDF) showed maximum growth and yield attributing traits. An increase of 11.54% in green fodder and 8.94% in dry matter yield was recorded over RDF only. Further, the inoculated plants were also higher in terms of energy use efficiency, energy productivity, output energy, and net energy. Kaur *et al*. (2025) also demonstrated that liquid bacterial inoculants of *B. seminalis* and *S. maltophilia,* along with 75% RDF, resulted in the highest productivity of sorghum forage, showing a 10.23% increase in pooled green fodder yield compared to the control.

Therefore, the need of the hour is the combined use of bacterial inoculants (biofertilizers) and chemical fertilizers, as biofertilizers are not a replacement for fertilizers, but they can supplement the requirement (Patra and Singh 2018) and, in optimum quantity, may help to increase the yield and growth attributes and energy efficiency in agriculture. Keeping the above points in view, the present study aimed to study the effect of inorganic and bio-fertilizers on the production potential and energy budgeting of fodder oats.

Materials and Methods

Experimental site and treatments: A field experiment was carried out during the *rabi* season of 2021-22 at two places of Punjab i.e. Punjab Agricultural University, Regional Research Station, Bathinda (30°09′′36′ N, 74°55′′28′ E and 211 m above sea level) and Department of Plant Breeding and Genetics, PAU, Ludhiana (30.9°N, 75.85°E and 244 m above sea level). At Bathinda and Ludhiana, mean monthly maximum temperatures during the crop season ranged from 14.2 to 26.6°C and 12.4 to 23.2°C, respectively. The mean monthly minimum temperatures varied from 3.4 to 11.2°C and 5.4 to 8.6°C, respectively. During the crop growing period, no rainfall was received and the mean monthly relative humidity varied from 50 to 94% and 44 to 97%, respectively. The soil of the experimental site at both locations was sandy loam and physicochemical analysis of the initial soil sample revealed 9.19 and 8.25 pH, 0.38 and 0.48 dS/m electrical conductivity, 0.29 and 0.48 % organic carbon, 187.6 and 318.54 kg ha^{-1} nitrogen, 13.50 and 16.75 kg ha^{-1} phosphorus and 246.50 and 292.50 kg ha^{-1} potassium at Bathinda and Ludhiana, respectively.

The pure cultures of *Burkholderia seminalis*, *Azotobacter* sp., *Stenotrophomonas maltophilia* and *Bacillus thaonhiensis* were procured from the School of Organic and Natural Farming, Punjab Agricultural University, Ludhiana and were preserved on Nutrient Agar medium. They were subcultured regularly throughout the period of investigation and maintained in refrigerated conditions for future use. These bacterial cultures are promising plant growth-promoting bacteria with plant growth-promoting features, i.e., indole acetic acid production, phosphate solubilization, ammonia production, gibberellic acid production and Siderophore production (Arora *et al*., 2024; Kaur and Pandove, 2025).

The experiment at each location (Bathinda and Ludhiana) was laid out in a randomized complete block design (RCBD) with eleven treatments in three replications. The different treatments were– T_1: RDF (recommended dose of fertilizer); T_2: RDF + *B. thaonhiensis*; T_3: RDF + *Azotobacter* sp.; T_4: RDF + *B. seminalis*; T_5: RDF + *S. maltophilia*; T_6: RDF + *B. thaonhiensis* + *Azotobacter* sp.; T_7: RDF + *B. thaonhiensis* + *B. seminalis*; T_8: RDF + *B. thaonhiensis* + *S. maltophilia*; T_9: RDF + *Azotobacter* sp. + *B. seminalis*; T_{10}: RDF + *Azotobacter* sp. + *S. maltophilia*; T_{11}: RDF + *B. seminalis* + *S. maltophilia*.

***Crop husbandry*:** Proper irrigation was provided to the experimental sites before sowing. Land preparations were carried out mechanically with due care to avoid mixing the soil of neighboring plots. The oat cultivar 'OL-11' single-cut variety was sown (25 kg ha^{-1}) in 20 cm row spacing using a one-row hand seed drill. All the chemical fertilizers were applied basally through urea and diammonium phosphate (DAP). Seed bacterization was done with *Burkholderia seminalis, Azotobacter* sp., *Stenotrophomonas maltophilia* and *Bacillus thaonhiensis* as per treatments @ 100 ml/acre for 30 minutes. The inoculated seeds were air-dried in the shade and were planted within two hours. Weeding and hoeing were performed to prevent unnecessary weeds and suitable control measures were taken to prevent the crop from pests and insects.

Energy analysis: Energy is the most important indication of crop yield. Therefore, energy analysis is required for the efficient management of scarce resources to improve agricultural production. The energy input (EI), energy output (EO) and specific energy (SE), net energy (NE), energy productivity (EP) and energy use efficiency (EUE) were computed as Mega Joules (MJ) by the following formulas:

Energy input was calculated by summing the energy equivalents for all inputs used in the system and represented in Table 1; EI = Ehl + Emt + Epr (Meyer-Aurich, 2005), where Ehl, Emt, and Epr stand for energy from human labor, materials such as seed, pesticides, fertilizer, biofertilizers and irrigation and power, respectively.

EO = Emp + Ebp (Meyer-Aurich, 2005), where Emp and Ebp stand for energy from the main product and by-product, respectively.

The energy use efficiency (EUE) of the crop was evaluated based on the energy ratio between output and input, which evaluates the efficiency of the system in using the energy supplied by the plant. Generally, higher energy input leads to lower energy use efficiency, while higher energy output results in higher energy use efficiency (ratio of energy output to total biomass and energy input).

EUE (%) = Energy output (MJ/ha)/ Energy input (MJ/ha) (Demircan *et al*.,2006)

Energy productivity (EP) is the mass of grain and straw yield per unit of fossil energy input, expressed in kg of grain and straw per MJ of energy input.

EP (kg/MJ) = Fodder Yield (kg/ha)/Total energy input (MJ/ha) (Kumar *et al*., 2021)

Specific energy denotes the ratio of energy input and grain yield of the crop.

SE (MJ/kg) = Energy input (MJ/ha)/Fodder yield (kg/ha) (Kumar *et al*., 2021)

Net energy represents the difference between the energy output and the total energy input.

NE= Gross energy output (MJ/ha)-Energy input (MJ/ha) (Harika *et al*., 2020)

***Statistical analysis*:** The randomized complete block design with three replications was employed for data analysis. All the statistical analyses were performed by the procedure described by Cochran and Cox (1967). The comparisons were made at a 5% level of significance. Correlation studies were carried out using SPSS Software. Likewise, the data pertaining to energy analysis was statistically analyzed by Duncan's multiple range test (DMRT) by using SAS software version 20.0 to show significant differences at $p \leq 0.05$.

Results and Discussion

***Yield attributes and crop yield*:** The various yield and yield attributes were recorded at both the locations, i.e., Bathinda and Ludhiana and the data regarding the same have been presented in Tables 2 and 3. Germination is the first main step of plant growth. Better germination resulted in better plant establishment, which ultimately translates into higher yields. It was found to be non-significant among the environment and treatments, but the same attribute was observed as highly significant for the interaction between treatments and environments

Table 1. Energy equivalents (MJ) of the inputs and outputs of the crop

Components	Units	Energy equivalents	References
Input			
Human labour (Male)	Man-hour	1.96	Soni *et al*. (2013)
Human labour (Female)	Female-hour	1.60	Soni *et al.* (2013)
Diesel	Litre	56.30	Nassiri and Singh (2009)
Electricity	KWh	11.93	Singh and Mittal (1992)
Cultivator	Hour	3.13	Nassiri and Singh (2009)
Tractor	Hour	64.80	Devasenapathy *et al*. (2009)
Sprayer	Hour	0.502	Nassiri and Singh (2009)
N	Kg	60.60	Kuswardhani *et al. (*2013)
P_2O_5	Kg	11.10	Chaudhary *et al*. (2009)
Biofertilizer	Kg or Litre	2.98	Mihov *et al. (*2012)
Pesticide	Kg	199.0	Brar *et al*. (2015)
Herbicides	Kg	238.0	Singh and Jha (2017)
Output			
Seed	Kg	14.70	Tuti *et al*. (2012)
Grain	Kg	14.70	Tuti *et al*. (2012)
Straw	Kg	12.50	Tuti *et al*. (2012)

during the pooled analysis (Table S1). These results were consistent with Artyszak and Gozdowski (2020), who demonstrated the significant interaction between treatments and environments on yield, technological quality of the roots and traits of sugar beet plants. The maximum germination count was recorded with the treatment T_{11} (198.85 m^{-2}), followed by the treatment T_7 (196.66 m^{-2}) in the pooled analysis. Moreover, the data were also analyzed for the individual locations and found that mean squares for germination were observed as non-significant for treatments, but a numeric increase in germination was observed at both locations, i.e., Bathinda and Ludhiana. The maximum germination count was recorded with the treatment T_{11} (201.07 and 196.64 m^{-2}) while the minimum was observed in the treatment T_1 (179.98 and 172.19 m^{-2}) at Bathinda and Ludhiana, respectively. The application of the treatment T_{11} resulted in a percent increase of 11.71 and 14.19 over T_1 at Bathinda and Ludhiana, respectively.

Plant height is an essential growth-related parameter that is directly related to plant productivity in terms of the forage yield of the crop. The mean squares among environments and interaction by environment and treatment were observed as significant and influenced the plant height during the pooled analysis. Amin *et al*. (2015) also stated that environmental changes (climate variables) had a significant influence on the yield and cropping area of crops with distinct variations among them. The maximum plant height was noted with the treatment T_{11} (133.40 cm), while the minimum was with the treatment T_1 (114.92 cm) in the pooled study. At the individual locations, the mean squares for plant height were observed as non-significant for treatments. The maximum plant height was observed in the treatment T_{11} (138.38 and 128.43 cm), while the minimum was in the treatment T_1 (118.66 and 111.18 cm) at Bathinda and Ludhiana, respectively. The treatment T_{11} indicated an approximate increase of 16.61% and 15.51% over the T_1 at Bathinda and Ludhiana, respectively. Our results corroborate the findings of Kaur and Goyal (2017).

Chlorophyll is an important photosynthetic pigment found in plants, which in turn directly affects the photosynthesis of the plants (Su *et al.,* 2017). During the pooled analysis, the mean squares among treatments and environments and treatments by environment interaction were observed as significant implies that all three factors can significantly influence the chlorophyll content. The significantly highest chlorophyll content was recorded by the treatment T_{11} (2.78 mg/g), followed by the treatment T_7 (2.64 mg/g) in the pooled analysis. Besides this, the mean squares were significant at Bathinda and Ludhiana for the treatments. The maximum chlorophyll content was attained by the treatment T_{11} (2.79 and 2.77 mg/g) while the minimum was in the treatment T_1 (2.18 and 2.14 mg/g) at Bathinda and Ludhiana, respectively. Our results were in close conformity with Ramya (2019), who reported chlorophyll content in the range of 1.47 to 2.22 mg/g in fodder cowpea.

The number of tillers per plant is an important yield parameter. The higher the number of tillers present, the higher will be the yield of fodder (Saleem *et al.*, 2015). The mean squares were non-significant for the environment and treatments. However, the same attribute was observed as highly significant for the interaction between treatments and environments during the pooled analysis. The maximum number of tillers per plant was observed with the treatment T_{11} (7.97), followed by T_7 (7.89) in the pooled analysis. At individual locations, mean squares were non-significant for the treatments. The maximum number of tillers per plant was recorded with the treatment T_{11} (8.00 and 7.94), followed by T_7 (7.95 and 7.83), while the minimum was in the treatment T_1 (6.83 and 6.55) at both locations, respectively. The percent amelioration of 17.13 and 21.22 was witnessed by the use of T_{11} over the T_1 at Bathinda and Ludhiana, respectively. The result of the present study corroborates the findings of Hameed *et al*. (2014), wherein they obtained the number of tillers per plant in the range of 5.56 to 7.93 in oat.

The total number of leaves plays a vital role in the overall growth and development of the plants, as the leaves serve as the basic factory for the production of food (Saleem *et al.,* 2015). The mean square was significant for the interaction between environment and treatment during the pooled analysis. Moreover, at individual locations, the mean squares were non-significant for the treatments, but numeric enhancement was observed in the number of leaves, with the maximum being observed in the treatment T_{11} (39.83 and 39.81), followed by the treatment T_7 (39.15 and 38.96) at Bathinda and Ludhiana, respectively. The percent elevation in the number of leaves with the application of treatments T_{11} with respect to T_1 was 17.52 and 18.44 at Bathinda and Ludhiana, respectively. This result was supported by Ayub *et al.* (2010) in cluster beans.

The leaf-to-stem ratio is an important yield contributing parameter and has a direct influence on the fresh green and dry yield of fodder oats. The results of the pooled analysis showed the significant impact among treatments and interaction between environments and treatment and indicate that treatment T_{11} (0.676) were having higher leaf to stem ratio over the RDF. Besides the pooled analysis for the two locations, the data were also analyzed for the individual location. At Bathinda and Ludhiana, the mean squares were obtained as non-significant for the treatments. The application of liquid bacterial inoculants resulted in the numeric enhancement in the leaf to stem ratio, with the highest being found in treatment T_{11} (0.677 and 0.675) and the lowest in T_1 (0.565 and 0.562) at Bathinda and Ludhiana, respectively. The percentage improvement by the application of T_{11} was 19.82 and

20.10 over the treatment T_1 at Bathinda and Ludhiana, respectively. The aforementioned results corroborate the findings of Kaur and Goyal (2017), where the leaf-to-stem ratio of oats is in the range of 0.52 to 0.73. Similar findings were observed in fodder maize (Sharma *et al.,* 2016) and oats (Dawit and Wegi, 2014).

Leaf breadth is an important yield parameter and the pooled data disclosed that significant mean squares were obtained among treatments and the interaction between treatments and environments. Arora *et al.* (2022) reported that bacterial treatments had a significant influence on the quality traits of pearl millet. In this, maximum leaf breadth was attained by the treatment T_{11} (2.45 cm), while the minimum was in the treatment T_1 (2.44 cm) in the pooled analysis. However, at the individual locations, the mean squares were obtained as statistically non-significant. The maximum leaf breadth was achieved by the treatment T_{11} (2.47 and 2.43 cm), while the minimum was in the treatment T_1 (1.84 and 1.79 cm) at Bathinda and Ludhiana, respectively. The aforementioned results corroborate the findings of Krishna *et al.* (2013), wherein they obtained the leaf breadth of oats in the range of 1.79-2.38.

Leaf length plays an important role in the final biomass and the quality of the crop and was found to be non-significant for the treatments, but the same was significant among environment and interaction between environment and treatment during the pooled analysis. The maximum leaf length was measured in the treatment T_{11} (48.79 cm), followed by the treatment T_7 (47.66 cm) in the pooled analysis. Moreover, the data was analyzed for the individual Bathinda and Ludhiana locations. In this, the mean squares were non-significant for the treatments, but a numeric increase was observed in the treatments. The maximum leaf length was exhibited by the treatment T_{11} (50.77 and 46.81 cm), followed by the treatment T_7 (49.55 and 45.77 cm) at both locations. The percent amelioration of 19.43 and 20.83 was witnessed by the use of T_{11} over the T_1 at Bathinda and Ludhiana, respectively. Our results were in accordance with Krishna *et al.* (2013), who observed the leaf length in different varieties of oats to be in the order of 33.56-57.26.

Dry matter accumulation per plant contains proteins, fibre, vitamins and minerals after the removal of all the water. The mean square was statistically significant for the treatments and the interaction between environment and treatment over the locations. However, at Bathinda and Ludhiana, respectively, the mean square was non-significant. At the individual locations, maximum dry matter accumulation per plant was recorded with the treatment T_{11} (62.63 and 61.81 g) while the minimum was with the treatment T_1 (53.16 and 53.09 g) at Bathinda and Ludhiana, respectively. The percent improvement in dry matter over T_1 with the application of T_{11} was 17.81 and 16.42, respectively. Alipatra *et al.* (2012) studied different fertilization treatments on fodder oats and observed the dry matter accumulation to be in the range of 38.06- 61.47 in the first cut.

Green fodder yield is the consequence of several complex physiological and morphological processes that take place during plant growth and development. The data of the pooled study showed that the mean square was significant for the interaction of environment and treatment. The maximum green fodder yield was recorded with the treatment T_{11} (70.35 t/ha), followed by the treatment T_7 (70.08 t/ha) in the pooled analysis. In addition, the analysis of variance at individual locations was found to be non-significant among the treatments. The maximum green fodder yield was attained with the treatment T_{11} (70.67 and 70.05 t/ha) while the minimum was with the treatment T_1 (63.35 and 62.21 t/ha) at Bathinda and Ludhiana, respectively. The percentage improvement in the green fodder yield by the application of T_{11} was 11.55 and 12.60 over the treatment T_1 at Bathinda and Ludhiana, respectively. Our results were on similar lines to Saleem *et al.* (2015) and Waheed *et al.* (2012) in Oats.

Dry matter yield is a measure of the photosynthetic efficiency of the assimilatory system of plants. It is the function of maximum nutrient accumulation in plant biomass, soil-nutrient status, genetic makeup and management strategies (Saleem *et al.,*2015). The pooled study showed that dry matter yield was non-significant among environments and treatments, but significant for the interaction between environment and treatment. Along with the pooled deviation, the variance was also analyzed at individual locations and was found to be non-significant for the treatments. The maximum dry matter yield was recorded with the treatment T_{11} (13.70 t/ha), while the minimum was with the treatment T_1 (11.94 t/ha) in the pooled analysis. The percentage improvement in the dry matter yield by the application of T_{11} was 13.79 and 15.61 over the treatment T_1 at Bathinda and Ludhiana, respectively. The results observed were in close association with Shabbir *et al.* (2013) in the fodder oats, where inoculation of seed with PSB gave more dry matter yield (14.69 t ha^{-1}) as compared to the uninoculated control.

The yield and yield attributes such as germination count, plant height, leaf length, leaf breadth, chlorophyll content, number of leaves per plant, leaf to stem ratio, number of tillers, dry matter accumulation, green forage and dry forage yield were found to be the maximum in the treatment T_{11}: RDF + *B. seminalis* + *S. maltophilia*. This might be due to the plant growth-promoting potential of *B. seminalis* and *S. maltophilia*. Hwang *et al*. (2021) also reported the plant growth-promoting attributes of *B. seminalis*. Likewise, Huda *et al*. (2022) reported the PGPR characteristics in *S. maltophilia*. The application of PGPB leads to better availability of macronutrients via

Table 2. Influence of liquid bacterial inoculants on yield and yield attributes of forage oats at Bathinda and Ludhiana

Treatments	Germination Count (m^{-2})			Plant height (cm)			Chlorophyll content (mg/g)			Number of tillers			Number of leaves			Leaf stem ratio		
	BTI	LDH	Pooled	BTI	LDH	Pooled	BTI	LDH	Pooled	BTI	LDH	Pooled	BTI	LDH	Pooled	BTI	LDH	Pooled
T_1	179.98	172.19	176.09	118.66	111.48	114.92	2.18	2.14	2.16	6.83	6.55	6.69	33.89	33.61	33.75	0.565	0.562	0.563
T_2	182.17	176.74	180.58	127.55	115.60	121.57	2.29	2.20	2.24	7.26	7.16	7.21	35.72	35.07	35.39	0.591	0.576	0.583
T_3	182.16	176.63	179.40	126.77	115.07	120.92	2.26	2.16	2.21	7.21	7.05	7.13	35.50	35.05	35.27	0.572	0.570	0.571
T_4	184.44	182.22	183.33	132.77	118.11	125.44	2.32	2.23	2.28	7.44	7.10	7.27	37.55	35.26	36.40	0.613	0.578	0.595
T_5	184.43	179.98	181.08	130.01	115.60	122.80	2.35	2.25	2.30	7.55	7.22	7.38	36.72	35.14	35.93	0.612	0.577	0.594
T_6	186.66	184.43	185.54	134.09	118.92	126.51	2.42	2.37	2.40	7.56	7.34	7.45	37.60	36.27	36.94	0.634	0.590	0.612
T_7	197.77	195.54	196.66	137.37	126.44	131.90	2.69	2.58	2.64	7.95	7.83	7.89	39.15	38.96	39.06	0.675	0.657	0.666
T_8	191.09	188.88	189.99	136.70	120.96	128.83	2.54	2.53	2.53	7.73	7.57	7.65	38.22	37.27	37.74	0.669	0.642	0.655
T_9	188.86	187.75	188.31	134.85	120.51	127.68	2.42	2.38	2.40	7.61	7.44	7.52	37.99	36.77	37.38	0.657	0.638	0.648
T_{10}	188.84	186.69	187.76	134.18	120.40	127.29	2.47	2.42	2.45	7.66	7.55	7.60	37.77	36.40	37.08	0.635	0.626	0.630
T_{11}	201.07	196.64	198.85	138.38	128.43	133.40	2.79	2.77	2.78	8.00	7.94	7.97	39.83	39.81	39.82	0.677	0.675	0.676
CD (T)	NS	NS	NS	NS	NS	NS	0.13	0.16	0.10	NS	NS	NS	NS	NS	NS	NS	NS	0.75
CD (E)			NS			6.16			0.42			NS			NS			NS
CD (T X E)			28.15			21.36			0.14			1.44			6.42			0.10

Treatment details are given under Materials and Methods; BTI: Bathinda; LDH: Ludhiana; T: Treatment; E: Environment; T × E: Interaction

Table 3. Influence of liquid bacterial inoculants on yield and yield attributes of forage oats at Bathinda and Ludhiana

Treatments	Leaf breadth (cm)			Leaf length (cm)			Dry matter accumulation per plant (g)			Green fodder yield (t/ha)			Dry matter yield (t/ha)		
	BTI	**LDH**	**Pooled**	**BTI**	**LDH**	**Pooled**	**BTI**	**LDH**	**Pooled**	**BTI**	**LDH**	**Pooled**	**BTI**	**LDH**	**Pooled**
T_1	1.84	1.79	1.82	42.51	38.74	40.63	53.16	53.09	53.12	63.35	62.21	62.78	12.11	11.78	11.94
T_2	1.97	1.90	1.94	43.94	40.19	42.06	55.70	54.63	55.16	63.52	62.28	63.10	12.16	11.86	11.99
T_3	1.88	1.88	1.88	43.44	39.55	41.49	55.67	54.30	54.99	63.50	62.52	63.00	12.13	11.80	11.98
T_4	2.22	2.10	2.16	45.22	42.66	43.94	55.71	54.90	55.89	64.02	63.67	63.84	12.42	11.91	12.16
T_5	2.11	2.07	2.09	44.66	41.77	43.22	56.27	55.51	55.30	63.83	63.50	63.66	12.23	12.00	12.11
T_6	2.27	2.16	2.21	45.33	43.10	44.22	58.44	57.82	58.13	64.33	63.83	64.08	12.53	12.31	12.42
T_7	2.46	2.43	2.45	49.55	45.77	47.66	62.56	61.12	61.84	70.33	69.83	70.08	13.74	13.60	13.67
T_8	2.32	2.31	2.31	46.83	44.66	45.74	62.07	60.97	61.52	70.17	68.95	69.55	13.74	13.57	13.65
T_9	2.32	2.30	2.31	46.33	44.10	45.21	60.34	60.33	60.96	65.00	65.00	65.00	13.50	13.36	13.42
T_{10}	2.28	2.27	2.28	45.55	43.81	44.68	61.15	60.77	60.33	64.97	64.25	64.61	13.40	12.89	13.14
T_{11}	2.47	2.43	2.44	50.77	46.81	48.79	62.63	61.81	62.22	70.67	70.05	70.35	13.78	13.62	13.70
CD (T)	NS	NS	0.27	NS	NS	NS	NS	NS	4.59	NS	NS	NS	NS	NS	NS
CD (E)			NS			2.25			NS			NS			NS
CD (T x E)			0.38			7.80			6.50			11.07			2.78

Treatment details are given under Materials and Methods; BTI: Bathinda; LDH: Ludhiana; T: Treatment; E: Environment; T × E: Interaction biological nitrogen fixation or phosphate solubilization and micronutrients via mineralization, along with the production of phytohormones such as indole acetic acid (IAA), gibberellins (GA_3) and cytokinins. The combined use of chemical and bio-fertilizers not only has an additive effect on the supply of nutrients, but also slows down the loss of N and conserves it through the formation of organo-mineral complexes, leading to a continuous supply of N, leading to higher yields (Deva 2015). Also, Tiwana and Chaudhary (2009) reported that biofertilizers activate some enzymes that may have played an important role in improving the forage yield, which enables the plant to draw more nutrients from the soil for adequate growth and development and the inoculated plants manufacture more quantity of photosynthates and thus result in the elevation of the dry matter yield. Several researchers, namely Singh and Dubey (2008), Ahmad *et al*. (2011), Devi *et al*. (2014), Duhan (2013) and Verma *et al*. (2016) found better green and dry forage yield in oats by the combined effect of inorganic and organic nutrient sources. Also, Prasad *et al*. (2012) evaluated the inoculation of *Rhizobium* + PSB along with 20kg N ha^{-1} in cowpea and considerably augmented growth factors such as crop growth rate, plant height, dry weight, number of roots per plant and yield contributing characteristics including seed index, grains per pod, pods per plant and grain and haulm yield. Garg *et al*. (2022) also demonstrated that the dual inoculation of biofertilizers (*Frankia* + PSB) along with 60 kg N and 50 kg P_2O_5 ha^{-1} resulted in enhanced shoot length, root length, collar diameter, shoot fresh weight, root fresh weight, shoot dry weight and root dry weight over other treatment combinations and control, i.e., uninoculated and unfertilized.

***Correlation*:** Correlation analysis is widely used to understand the complex inter-relationships between traits and to identify sources of yield variability (Finne *et al*., 2000). Correlation analysis of various yield attributing traits with yield was performed at Bathinda and Ludhiana to assess the degree of association between the traits (Fig 1). Under all the bacterial treatments, the green fodder yield showed a significant correlation with the yield attributes, i.e. chlorophyll content (0.93), emergence count (0.91), leaf to stem ratio (0.88), number of leaves per plant (0.86), dry matter accumulation per plant (0.85), number of tillers per plant (0.83), leaf breadth (0.83), leaf length (0.82), plant height (0.61), and implying their promising contribution on the yield of fodder oats. Similarly, dry matter yield showed a positive correlation with the yield attributing traits. Tariq *et al*. (2012) and Amare *et al*. (2015) demonstrated a significantly positive correlation between green fodder yields and other fodder-yield attributes. Kaur *et al*. (2020) also reported a significant positive correlation of green fodder yield with the plant height and leaves per plant.

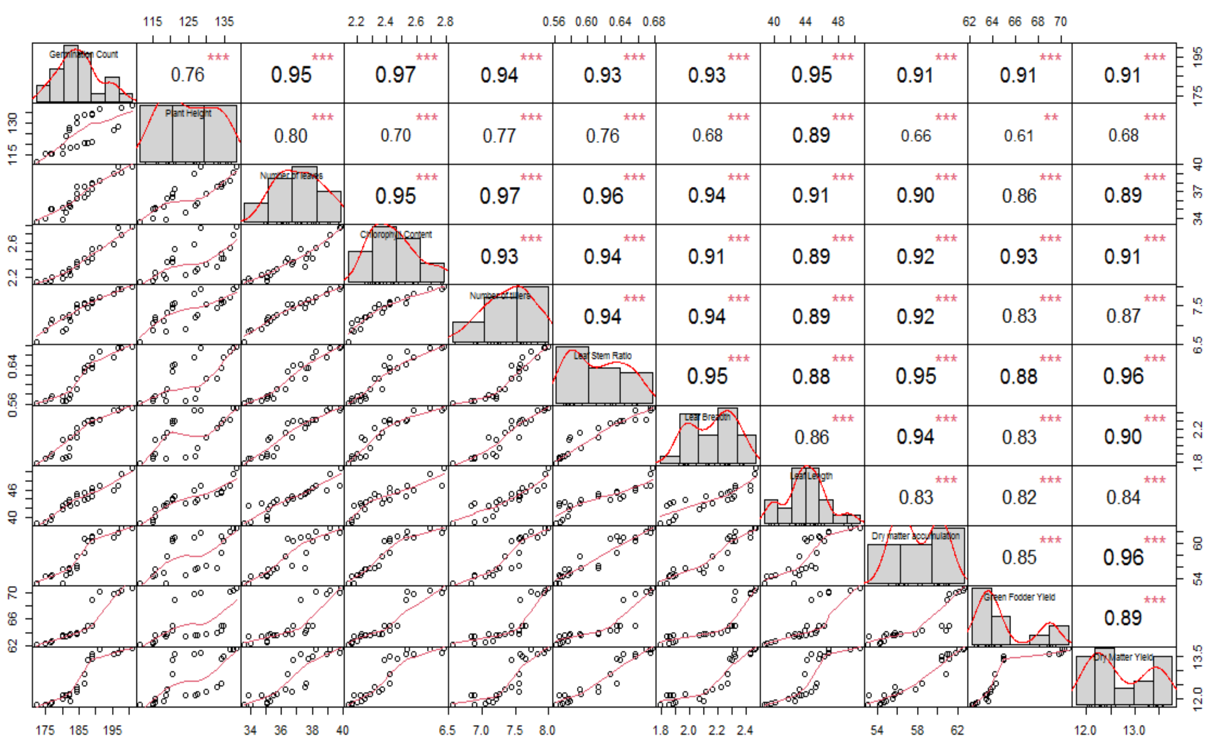

Fig 1. The correlation between yield and yield attributing traits of forage oats as influenced by various liquid bacterial inoculants at Bathinda and Ludhiana

Table 4. Impact of liquid bacterial inoculants on energetics of fodder oats at Ludhiana

	Treatments	Energy output	Energy input	SE	EP	EUE	NE
T_1	RDF	781269.0^{g}	5511.30^{b}	0.101968^{a}	9.69503^{e}	121.0349^{i}	770302.1^{e}
T_2	RDF + *B. thaonhiensis*	781905.7^{g}	5514.28^{a}	0.101129^{ab}	9.84818^{d}	122.9208^{gh}	772968.9^{e}
T_3	RDF + *Azotobacter* sp.	781650.6^{g}	5514.28^{a}	0.101343^{ab}	9.82926^{d}	122.4340g^{hi}	770443.3^{e}
T_4	RDF + *B. seminalis*	800122.5^{e}	5514.28^{a}	0.101071^{ab}	9.90113^{d}	123.9278^{fg}	779310.4^{e}
T_5	RDF + *S. maltophilia*	783240.3^{f}	5514.28^{a}	0.101118^{a}	9.86720^{d}	123.9098^{fg}	778553.0^{e}
T_6	RDF + *B. thaonhiensis* + *Azotobacter* sp.	804241.5^{d}	5514.28^{a}	0.100027^{bc}	10.06393^{c}	124.9645^{ef}	783620.5^{e}
T_7	RDF + *B. thaonhiensis* + *B. seminalis*	835352.3^{b}	5514.28^{a}	0.891438^{f}	11.14777^{b}	138.3274^{b}	883545.4^{b}
T_8	RDF + *B. thaonhiensis* + *S. maltophilia*	812505.0^{c}	5514.28^{a}	0.912464^{e}	11.13192^{b}	136.7277^{c}	864152.9^{c}
T_9	RDF + *Azotobacter* sp. + *B. seminalis*	812272.0^{c}	5514.28^{a}	0.984047^{d}	10.09998^{c}	126.8474^{d}	816225.4^{d}
T_{10}	RDF + *Azotobacter* sp. + *S. maltophilia*	811784.3^{c}	5514.28^{a}	0.988084^{cd}	10.06572^{c}	125.5622^{de}	808174.9^{d}
T_{11}	RDF + *B. seminalis* + *S. maltophilia*	863972.0^{a}	5514.28^{a}	0.876590^{g}	11.44272^{a}	142.7077^{a}	917617.0^{a}

Table 5. Impact of liquid bacterial inoculants on energetics of fodder oats at Bathinda

	Treatments	Energy output	Energy input	SE	EP	EUE	NE
T_1	RDF	751460.^{5}h	5511.30^{b}	0.104385^{e}	9.21710^{f}	117.5152^{e}	759510.8^{f}
T_2	RDF + *B. thaonhiensis*	781236.8^{f}	5514.28^{a}	0.102343^{a}	9.55485^{de}	121.4601^{d}	771406.7^{e}
T_3	RDF + *Azotobacter* sp.	765358.5^{g}	5514.28^{a}	0.102905^{a}	9.47063^{ef}	118.7490^{e}	770930.0^{ef}
T_4	RDF + *B. seminalis*	781475.1^{e}	5514.28^{a}	0.102019^{b}	9.67533^{de}	122.4439^{d}	777480.6^{e}
T_5	RDF + *S. maltophilia*	781314.1^{f}	5514.28^{a}	0.103137^{ab}	9.65016^{de}	121.5804^{d}	776449.3^{de}
T_6	RDF + *B. thaonhiensis* + *Azotobacter* sp.	781556.1^{e}	5514.28^{a}	0.101609^{b}	9.77508^{de}	122.5976^{d}	780882.7^{de}
T_7	RDF + *B. thaonhiensis* + *B. seminalis*	811466.6^{b}	5514.28^{a}	0.091869^{d}	11.13143^{a}	136.0855^{b}	874100.1^{b}
T_8	RDF + *B. thaonhiensis* + *S. maltophilia*	790027.1^{c}	5514.28^{a}	0.092859^{d}	10.71253^{b}	135.9421^{b}	864639.9^{b}
T_9	RDF + *Azotobacter* sp. + *B. seminalis*	790018.1^{c}	5514.28^{a}	0.099089^{c}	10.10902^{c}	125.6420^{c}	808691.8^{c}
T_{10}	RDF + *Azotobacter* sp. + *S. maltophilia*	781772.0^{d}	5514.28^{a}	0.101461^{b}	9.81000^{d}	123.2007^{d}	787515.9^{d}
T_{11}	RDF + *B. seminalis* + *S. maltophilia*	851476.^{5}a	5514.28^{a}	0.089044^{d}	11.22850^{a}	140.4334^{a}	917316.3^{a}

Energetics**:** The energetics parameters like energy input, energy output, energy use efficiency (%), net energy, energy productivity and specific energy of oats were calculated and have been presented in Tables 4 and 5. The energy input ranged from 5511.3 to 5514.28 MJ/ha at Ludhiana as well as Bathinda; it may vary due to differences in energy use under different treatments. The magnitude of energy output ranged from 781269.0 to 863972.0 MJ/ha and 751460.5 to 851476.5MJ/ha at Bathinda and Ludhiana, respectively. The highest energy output was obtained with the treatment T_{11} at Bathinda and Ludhiana, respectively. The lowest energy output was noted with the treatment devoid of liquid bacterial inoculants. The energy output depends on the green fodder yield in different treatments and a higher yield manifested greater energy output. Kumar *et al*. (2021) also reported the highest energy output, i.e., 160207 and 150042.4 MJ/ha at Bathinda and Ludhiana, respectively, in the treatment that received 87.5% N, 87.5% P and bio fertilizer in wheat crop. Similarly, the treatment T_{11} manifested higher energy productivity (11.44272 and 11.22850 kg MJ^{-1}) and energy use efficiency (142.7077 and 140.4334) at Bathinda and Ludhiana, respectively, as compared to other treatments. This might be due to an increase in energy output with regard to energy input, leading to more efficient use of energy.

The specific energy is an important index that indicates how much energy is used to produce one unit of grain. In the present study, it has been calculated per unit of green fodder yield. The maximum specific energy was found in the treatment T_1 (0.101968 and 0.104385 MJ/kg), while the lowest was in the treatment T_{11} (0.876590 and 0.089044 MJ/kg). All the inoculated treatments showed the lowest specific energy over the uninoculated treatment (T_1). The maximum net energy was found in the treatment T_{11} (917617.0 and 917316.3 MJ/ha) and the minimum in the treatment T_1 (770302.1 and 759510.8 MJ/ha) at Bathinda and Ludhiana, respectively. This might be due to a positive increase in gross power output as compared to energy input.

Sustainable agriculture requires proficient management of energy inputs. All the energy parameters were found to be the highest in the inoculated treatment as compared to the RDF. This might be attributed to the increase in fodder yield in the aforesaid treatments due to the efficient utilization of the nutrients by the inoculated bacteria. Beneficial bacterial-assisted nutrient management is a sustainable, cost-effective and ecological option in various agro-ecosystems, i.e., intensive, organic and integrated systems. These practices protect the environment from nutrient losses (denitrification, runoff) and pollution (soil degradation, eutrophication). The rhizospheric interaction mobilizes nutrients and increases nutrient use efficiency (Meena *et al*., 2016). Mihov and Tringovska (2010) demonstrated that in tomato cultivation the application of biofertilizer increased the energy input (100.30 GJ /ha), output (119.48 GJ/ ha), output-input ratio (1.19), energy productivity (0.99 kg/ MJ) than the RDF (98.45 GJ/ha, 90.52 GJ/ ha, 0.92 kg/ MJ and 0.77 kg/ MJ respectively). Similarly, Pal *et al*. (2018) observed that bio-priming by *T. harzianum* (NBRI 1055) improved the energy saving of 970 to 1670 KJ in okra production as compared to RDF, i.e., 100% chemical fertilizers, which consumed about 4320 KJ/unit energy.

Conclusion

This study concluded that the bioformulation of liquid bacterial inoculants, i.e., *Bacillus thaonhiensis*, *Azotobacter* sp., *Stenotrophomonas maltophilia* and *Burkholderia seminalis* alone or in various combinations along with the recommended dose of fertilizer, improved the productivity and energy-budgeting of forage oats. The seed bacterization with the treatment T_{11}: RDF + *B. seminalis* + *S. maltophilia* is observed to be the most superior. Therefore, if applied consistently over a long period of time, these bacterial inoculants could play an essential role in improving the productivity of forage oats while simultaneously improving the energy produced and thus increasing animal productivity.

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References

Ahmad, A. H., A. Wahid, F. Khalid, N. Fiaz and M. S. I. Zamir. 2011. Impact of organic and inorganic sources of nitrogen and phosphorous fertilizers on growth, yield and quality of fodder oat (*Avena sativa* L.) *Cercetari Agronomice in Moldova* 44: 39-49.

Alipatra, A., C.K. Kundu, P. Bandhopadhyay, P.S. Bera and H. Banerjee H. 2012. Growth, yield and quality of fodder oat (*Avena sativa* L.) as affected by split application of fertilizer and cutting management. *Crop Research* 43: 234-237.

Amare, K., H. Zeleke and G. Bultosa. 2015. Variability for yield, yield related traits and association among traits of sorghum [*Sorghum bicolor* (L.) Moench] varieties in Wollo, Ethiopia. *Journal of Plant Breeding and Crop Science* 7: 125-133.

Amin, M.R., J. Zhang and M. Yang. 2015. Effects of climate change on the yield and cropping area of major food crops: A case of Bangladesh. *Sustainability* 7: 898-915.

Anon. 2018. National Accounts Statistics 2016. Central statistical conference.

Arora, V., G. Pandove, H. Oberoi, S. Kaur and A. Kalia. 2022. Amelioration in the quality traits of forage pearl millet (*Pennisetum glaucum*) by application of liquid microbial inoculants. *Indian Journal of Animal Sciences* 92: 599–603.

Arora, V., G. Pandove, S.K. Brar, H. K. Oberoi and A. Kalia. 2024a .Productivity and energetics of forage pearl millet as influenced by liquid microbial inoculants. *Range Management and Agroforestry* 45: 366-371.

Arora, V., G. Pandove, S.K. Brar, H.K. Oberoi and A. Kalia. 2024b. Evaluating plant growthpromoting rhizobacteria to improve the productivity of forage pearl millet. *Current Microbiology* 81:172 https://doi.org/10.1007/s00284-024-03701-0.

Artyszak, A. and D. Gozdowski. 2020. The effect of growth activators and plant growth-promoting rhizobacteria (PGPR) on the soil properties, root yield, and technological quality of sugar beet. *Agronomy* 10: 1262.

Ayub, M., M. Tahir, M. A. Nadeem, M.A. Zubair, M. Tariq and M. Ibrahim. 2010. Effect of nitrogen application on growth, fodder yield and quality of three cluster bean varieties. *Pak Journal of life and social science* 8: 111-116.

Brar, A.S., G.S. Buttar, D. Jhanji, N. Sharma, K.K. Vashist, S.S. Mahal, J.S. Deol and G. Singh. 2015. Water productivity, energy and economic analysis of transplanting methods with different irrigation regimes in Basmati rice (*Oryza sativa* L.) under north-western India. *Agricultural Water Management* 158: 189-195.

Chakraborty, J., R. N. Arora, U.N. Joshi and A. K. Chhabra. 2014. Evaluation of *Avena* species for yield, quality attributes and diseases reaction. *Forage Research* 39: 179-184.

Chaudhary, V.P., B. Gangwar, D.K. Pandey and K.S. Gangwar. 2009. Energy auditing of diversified Paddy-wheat cropping systems in Indo-Gangetic plains. *Energy* 34: 1091-1096.

Cochran, W. G. and G. M. Cox. 1957. *Experimental Designs*. Asia Publishing House, Bombay.

Dalgaard, T., N. Halberg and J.R. Porter. 2001. A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. *Agriculture, ecosystems and environment* 87: 51-65.

Dawit, A. and T. Wegi. 2014. Determination of optimum seed and fertilizer rate for fodder Oat in Bale Highland South eastern Ethiopia. *International journal of Soil and Crop Science* 2: 73-76.

Demircan, V., K. Ekinci, M. H. Keener, D. Akbolat and C. Ekinci. 2006. Energy and economic analysis of sweet cherry production in Turkey: a case study from Isparata province. *Energy Conversion and Manag*ement 7: 1761-1769.

Deva, S. 2015. Effect of tillage practices and nutrient management on fodder yield of oat, soil fertility and microbial population. *The Bioscan* 10: 173-176.

Devasenapathy, P., G. Senthilkumar and P.M. Shanmugam. 2009. Energy management in crop production. *Indian Journal of Agronomy* 54: 80-90.

Devi, U., K. P. Singh, S. Kumar and M. Sewhag. 2014. Effect of nitrogen levels, organic manures and *Azotobacter* inoculation on yield and economics of multi-cut oats. *Forage Research* 40: 36-43.

Duhan, B. S. 2013. Effect of integrated nutrient management on yield and nutrients uptake by sorghum (Sorghum bicolor l.). *Forage Research* 39: 156-158.

Finne, M.A., O.A. Rognli and I. Schjelderup. 2000. Genetic variation in a Norwegian germplasm collection of white clover (*Trifolium repens* L.): Correlation and path coefficient analyses of agronomic characters. *Euphytica* 112: 57-68.

Garg, R. K., R. K. Garg and S. Sharma. 2022. Growth, biomass and nutrient uptake in *Casuarina junghuhniana* Miq. as influenced by applications of inorganic and biofertilizers *Range Management and Agroforestry* 43: 269-275.

Hameed, S., M. Ayub, M. Tahir, S. Khan and M. Bilal. 2014. Forage yield and quality response of Oat (*Avena sativa* L.) cultivators to different sowing techniques. *International Journal of Modern Agriculture* 3: 25-33.

Harika, J.V., S. K. Duvvada, S. Maitra and T. Shankar. 2020. Energetics of finger millet (*Eleusine coracana* L. gaertn) cultivation as influenced by integrated nutrient management. *International Journal of Agriculture, Environment and Biotechnology* 13: 227-230.

Huda, N. U., R. Tanvir, J. Badar, I. Ali, Y. Rehman. 2022. Arsenic-resistant plant growth promoting *Pseudoxanthomonas mexicana* S254 and *Stenotrophomonas maltophilia* S255 isolated from agriculture soil contaminated by industrial effluent. *Sustainability* 14: 10697.

Hwang, H. H., P. R. Chien, F. C. Huang, S. H. Hung, C. H. Kuo, W. L. Deng, E. P.I. Chiang, C.C. Huang. 2021. A plant endophytic bacterium, *burkholderia seminalis* strain 869t2, promotes plant growth in *Arabidopsis*, pak choi, chinese amaranth, lettuces, and other vegetables. *Microorganisms* 9: 1703.

Jat, H., M. L. Kaushik, V. Nepalia and D. Singh. 2017. Effect of irrigation schedule and nitrogen fertilization on growth, yield and quality of fodder oats (*Avena sativa* L.). *Journal of Pharmacognosy and Phytochemistry* 6: 2040-2042.

Kaur, G. and M. Goyal. 2017. Effect of growth stages and fertility levels on growth, yield and quality of fodder oats (*Avena sativa* L.). *Journal of Applied and Native Science* 9: 1287-1296.

Kaur, J and G. Pandove. 2025. Alleviation of saline stress by the bio-priming of cotton (*Gossypium hirsutum*) seeds with prominent indigenous bacterial isolates under axenic conditions, *Journal of Plant Nutrition.* DOI: 10.1080/01904167.2025.2493327.

Kaur, J., G. Pandove, A. S. Sidhu, S. K. Brar, N. D. Singh, V. Arora, and S. S. Walia. 2025. Characterization, identification, and biosafety evaluation of multifaceted traits of plant growthpromoting endophytes for ameliorating productivity of forage sorghum. *Current Microbiology* 82:101.

Kaur, O.H., G. Pandove and A. Kaur. 2020. Effect of pre-sowing seed inoculation with liquid biofertilizers on fodder yield and quality of sorghum (*Sorghum bicolor*). *Indian Journal of Agronom*y 65: 100-106.

Krishna, A., S. Ahmed, H.C. Pandey and D. Bahukhandi. 2013. Estimates of Genetic variability, heritability and genetic advance of oat (*Avena sativa* L.) genotypes for grain and fodder yield. *Agricultural Science Research* 3: 56-61.

Kumar, P., S. K. Brar, G. Pandove and C. S. Aulakh. 2021. Bioformulation of *Azotobacter* spp. and Streptomyces badius on the productivity, economics and energetics of wheat (*Triticum aestivum* L.). *Energy* 232: 120868.

Kuswardhani, N., P. Soni and G.P. Shivakoti. 2013. Comparative energy input–output and financial analyses of greenhouse and open field vegetable production in West Java, Indonesia. *Energy* 53: 83-92.

Meena, S.K., A. Rakshit and V.S. Meena. 2016. Effect of seed bio-priming and N doses under varied soil type on nitrogen use efficiency (NUE) of wheat (*Triticum aestivum* L.) under greenhouse conditions. *Biocatalysis and Agricultural Biotechnology* 6: 68-75.

Meyer-Aurich, A. 2005. Economic and environmental analysis of 341 sustainable farming practices- a Bavarian case study. *Agricultural Systems* 342: 190-206.

Mihov, M. and I. *Tringovska*. 2010. Efficiency improvement of greenhouse tomato production by applying new biofertilizers. *Bulgarian Journal of Agricultural Science* 16: 454-458.

Mihov, M., G. Antonova, S. Masheva and V. Yankova. 2012. Energy assessment of conventional and organic production of head cabbage. *Bulgarin Journal of Agricultural Sciences* 18: 320-324.

Nassiri, S.M. and S. Singh. 2009. Study on energy use efficiency for paddy crop using data envelopment analysis (DEA) technique. *Applied Energy* 86: 1320-1325.

Nasso, D.N.N., S. Bosco, D.C. Bene, A. Coli, M. Mazzoncini and E. Bonari. 2011. Energy efficiency in long-term Mediterranean cropping systems with different management intensities. *Energy* 36: 1924-1930.

Pal, S. and H.B. Singh. 2018. Energy inputs and yield relationship in greenhouse okra production by bio-priming. *International Journal of Agriculture, Environment and Biotechnology* 11: 741-746.

Patra, B. and B. Singh. 2018. Effect of priming, biofertilizers and nitrogen levels on yield and nutrient uptake by wheat. *International Journal of Microbiology and Applied Science* 7:1411e7.

Prasad, M., J. Dawson and R.S. Yadav. 2012. Effect of different nitrogen sources and phosphate solubilizing bacteria on growth and yield of grain cowpea [*Vigna unguiculata* (L.) Walp.]. *Crop Research* 44: 59-62.

Ramya, S. 2019. *Integrated Nutrient Management in Forage Cowpea with Application of Microbial Biotechnology (Liquid Microbial Inoculants).* M.Sc Thesis, Punjab Agricultural University, Ludhiana, India.

Roy, A.K., R.K. Agrawal, N. R. Bhardwaj, A. K. Mishra and S.K. Mahanta. 2019. Revisiting national forage demand and availability scenario. In: A.K. Roy, R.K. Agrawal and N.R. Bhardwaj (eds). *Indian Fodder Scenario: Redefining State Wise Status*. ICAR- AICRP on Forage Crops and Utilization, Jhansi, India, 1-21.

Saleem, M., M.S. I. Zamir, I. Haq, M.Z., M.K. Khan, M. Asim, Q. Zaman, I. Ali, A. Khan and S. Rehman. 2015. Yield and quality of forage oat (*Avena sativa* L.) cultivators as affected by seed inoculation with nitrogeneous strains. *American Journal of Applied Science* 6: 3251-3259.

Sarkar, D., A. Rakshit, A.I. Al-Turki, R.Z. Sayyed and R. Datta R. 2021. Connecting bio-priming approach with integrated nutrient management for improved nutrient use efficiency in crop species. *Agriculture* 11: 1-18.

Shabbir, I., M. Ayub, M. Tahir and R. Ahmad R. 2013. Effect of phosphorus solubilizing bacterial inoculation and phosphorus fertilizer application on forage yield and quality of oat (*Avena sativa* L.). *International Journal of Modern Agriculture* 2: 85-94.

Sharma, P. K., V. K. Kalra and U. S. Tiwana. 2016. Effect of farmyard manure and nitrogen levels on growth, quality and fodder yield of summer maize (*Zea mays* L.). *Agricultural Research* 53: 355-359.

Singh, R., S. Babu, R. K. Avasthe, G. S. Yadav and D. J. Rajkhowa. 2015. Influence of tillage and organic nutrient management practices on productivity, profitability and energetics of vegetable pea (*Pisum sativum* L.) in rice-vegetable pea sequence under hilly ecosystems of north-east India. *Research on Crops* 16: 683-688.

Singh, R.P. and P. N. Jha. 2017. The PGPR *Stenotrophomonas maltophilia* SBP-9 augments resistance against biotic and abiotic stress in wheat plants. *Front Microbiology* 8: 1945.

Singh, S. and J. P. Mittal. 1992. *Energy in Production Agriculture*. Mittal Publications, New Delhi, pp. 8-9.

Singh, S. D. and S. N. Dubey. 2008. Efficiency of *Azotobacter* to enhance the growth and yield of fodder oat *(Avena sativa* L.) under different levels of nitrogen and FYM. *Forage Research* 34: 116-118.

Soni, P., C. Taewichit and V. M. Salokhe. 2013. Energy consumption and CO2 emissions in rain-fed agricultural production systems of Northeast Thailand. *Agricultural Systems* 116: 25–36.

Su, F., S. Villaume, F. Rabenoelina, J. Crouzet, C. Clement, N. Vaillant-Gaveau and S. Dhondt-Cordelier. 2017. Different Arabidopsis thaliana photosynthetic and defense responses to hemibiotrophic pathogen induced by local or distal inoculation of *Burkholderia phytofirmans*. *Photosynthesis Research 1*34: 201-214.

Surje, D. T., S. D. Barma, S. B. Satpute, V. A. Kale, A. Das and D. K. De. 2015. Variability and cause effect analysis for fodder and grain yield characters in Oat (*Avena sativa* L.) Genotypes. *Forage Research*. 41:85-91.

Tariq, A.S., Z. Akram, G. Shabbir, M. Gulfraz, K.S. Khan, M.S. Iqbal and T. Mahmood. 2012. Character association and inheritance studies of different sorghum genotypes for fodder yield and quality under irrigated and rainfed conditions. *African Journal of Biotechnology* 11: 189-195.

Tiwana, U. S. and D. P. Chaudhary. 2009. Effect of integrated nutrient management on the yield and quality of forage sorghum. *Forage Research* 35: 56-58.

Tuti, M.D., B. M. Ved Prakash, R. Pandey, D. Bhattacharyya, J. K. Mahanta, M. K. Bisht, B. L. Mina, N. Kumar, J. C. Bhatt and A. K. Srivastva. 2012. Energy budgeting of colocasia-based cropping systems in the Indian sub-Himalayas. *Energy* 45: 986-993.

Verma, C., J. D. Thanki, D. Singh and S. N. Chaudhari. 2016. Effect of nitrogen, biofertilizer and farm yard manure on yield and nutrient uptake in Oat (*Avena Sativa* L.). *Bioinfolet* 11: 499-501.

Waheed, A., W. Ahmad, M.A. Shehzad and M. Shahid. 2012. Nitrogen and phosphorus: impact on forage oat (*Avena sativa* L.) growth, yield and its quality attributes. *Pakistan journal of agricultural science* 49: 473-479.

Yadav, S. K. and S. Babu, Y. Singh, G. S. Yadav, K. Singh, R. Singh and H. Singh. 2013. Effect of organic nitrogen sources and biofertilizers on production potential and energy budgeting of rice (*Oryza sativa*)-based cropping systems. *Indian Journal of Agronomy* 58: 9-14.