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Short communication

Productivity and energetics of forage pearl millet as influenced by liquid microbial inoculants

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Abstract

In the present study, an appraisal of liquid microbial inoculants on the productivity and energetics of forage pearl millet was carried out. The experiment was laid out in a randomized complete block design consisting of 12 treatment combinations of liquid microbial inoculants (*Azotobacter* sp., *Sphingobacterium* sp., *Stenotrophomonas maltophilia,* and *Burkholderia seminalis*) along with a 100% recommended dose of fertilizer (RDF) and replicated thrice. It was observed that treatment T_9: RDF + *B. seminalis* + *S. maltophilia* showed maximum growth and yield attributing traits. An increase of 11.54% in green fodder yield and 8.94% in dry matter yield was recorded with the application of T_9 over T_1: RDF (control). Further, the inoculated plants were also higher in terms of energy use efficiency, energy productivity, output energy, and net energy.

Keywords: Energy analysis, Microbial inoculants, Pearl millet, Productivity

India supports nearly 20% of the world's livestock population on just 2.2% of the world's geographical area. This puts pressure to increase fodder production for a healthy livestock population. The only way to meet the fodder needs of livestock is to look for increased productivity per unit of land area and also through the integration of fodder crops in the cropping system. The total green fodder availability is 734.2 million tonnes and dry fodder availability is 326.4 million tonnes, while the requirement sits at 827.19 million tonnes and 426.1 million tonnes, respectively (Roy *et al.,* 2019). In this context, Pearl millet (*Pennisetum glaucum* L.) is largely grown for grain and fodder purposes. Indeed, pearl millet is an essential source of fodder and a valuable feed for livestock (Meena and Nagar, 2018). Globally, it ranks sixth in terms of area and shares 42% of total world production. India is the largest producer of pearl millet in terms of production (10.05 mt) with average productivity of 1156 kg ha^{-1} and the total area under cultivated green fodder is 0.9 million hectares and the green fodder productivity is 21.34 tonnes per hectare. It is adapted to stress-intensive environments, versatile, input-responsive and high-quality cereal with great potential to become a valuable component of a non-traditional season like summer under irrigated and high input management conditions (Jakhar *et al.,* 2013).

Energy is an important, valuable input for production in agriculture. Agriculture is also an energy user and energy supplier in the form of bioenergy. Energy is an important indicator of crop performance and provides financial savings, fossil resource preservation and air pollution reduction (Yadav *et al.,* 2017). The availability of sufficient energy and its effective and efficient use are prerequisites for improved agricultural production. Energy analysis, therefore, is necessary for the efficient management of scarce resources for improved agricultural production.

The rapid increase in productivity with intensive use of non-renewable energy sources has very short-term advantages and must balance with long-term cost to the society as a whole for depleting the resources. Therefore, the adoption of an integrated approach for nutrient management offers the most potential measures to minimize the dependency on non-renewable energy, leading to an increased share of renewable energy, which will pave the way for sustainability. Hence, the need of hour is the integrated use of inorganic fertilizers and microbial inoculants which are not only environment friendly but also maintain the soil fertility. Microorganisms present in the soil can also serve as a promising choice for use as microbial inoculants. Soil is the largest source of microorganisms, including bacteria, fungi, and protozoa, among which bacteria are known to be the most abundant and varied.

Plant growth-promoting rhizobacteria (PGPR) are a heterogeneous group of rhizospheric bacteria that enhance plant growth through one or a series of specific mechanisms (Baset Mia *et al.,* 2010) such as siderophore production, biological nitrogen fixation, phosphate solubilization, production of 1-aminocyclopropane-1-carboxylate (ACC) deaminase, phytohormone, expressing antifungal activity, initiation of systemic resistance, and interfere with pathogen toxin production etc. Furthermore, these could play a salient part in adaptation strategies and elevate tolerance to abiotic stresses in agricultural plants due to climatic change. Now, formulations of PGPR are available as microbial inoculants or biofertilizers. The role of biofertilizers alone or in combination with organic or inorganic fertilizers has recently gained recognition in sustainable crop production. Therefore, in the present investigation, four potential bacterial cultures, i.e., *Azotobacter* sp., *Sphingobacterium* sp., *Stenotrophomonas maltophilia* and *Burkholderia seminalis* were applied on forage pearl millet under field conditions at two locations, *i.e*., Bathinda and Ludhiana and their influence on the yield attributes were recorded along with an analysis on energy.

Pure cultures of *Azotobacter* sp., *Sphingobacterium* sp., *S. maltophilia* and *B. seminalis* were procured from the Department of Microbiology, Punjab Agricultural University, Ludhiana, Punjab, India. The experiment was laid out in randomized complete block design (RCBD) with twelve treatments and replicated thrice at both locations *i.e.* Bathinda and Ludhiana, respectively. The different treatments were as follows, T_1: Recommended dose of fertilizer (RDF), T_2: RDF + *Azotobacter* sp., T_3: RDF+ *B. seminalis*, T_4: RDF+ *S. maltophilia*, T_5: RDF + *Sphingobacterium* sp., T_6: RDF + *Azotobacter* sp. + *B. seminalis*, T_7: RDF + *Azotobacter* sp.+ *S. maltophilia*, T_8 : RDF + *Azotobacter* sp.+ *Sphingobacterium* sp., T_9: RDF + *B. seminalis* + *S. maltophilia*, T_{10}: RDF + *B. seminalis* + *Sphingobacterium* sp., T_{11}: RDF + *S. maltophilia* + *Sphingobacterium* sp. and T_{12}: RDF + Consortium (commercially available biofertilizer from the Department of Microbiology, Punjab Agricultural University, Ludhiana). The land preparations were done mechanically with proper care to avoid mixing soil from adjacent plots. The pearl millet cultivar 'FBC-16' was sown at the rate of 8 kg/acre. Pearl millet seeds were inoculated with liquid microbial inoculants of *Azotobacter* sp., *Sphingobacterium* sp., *S. maltophilia* and *B. seminalis* as per treatments @ 100 mL/acre and the microbial population at the time of application was 10^8 cfu/mL. Inoculated seeds were air-dried in the shade and planted within 2 hours. Weeding and hoeing were done so as to avoid weeds and appropriate control measures were taken to prevent insects and pests. Other cultural operations and plant protection measures were followed as per the recommendations.

The influence of different combinations of liquid microbial inoculants was studied on the agronomic traits of forage pearl millet, namely, emergence count, plant height, number of leaves per plant, chlorophyll content, leaf-to-stem ratio, leaf breadth, leaf length and dry matter accumulation per plant at harvest.

The energy ratio between energy output and input evaluates the energetic efficiency of any crop. Based on the energy equivalents of inputs and outputs in crops (Table 1), the energy ratio (energy use efficiency), energy productivity and specific energy were calculated (Demircan *et al*., 2006; Sartori *et al*., 2005). Energy use efficiency (EUE) was calculated as the ratio between energy output and energy input that evaluates the system efficiency in using the energy supplied by crop [EUE = Energy output (MJ ha^{-1})/ Energy input (MJ ha^{-1})]. Energy productivity (EP) was the mass of grain yield per unit of fossil energy input expressed in kg grain per MJ energy input [EP (kg MJ^{-1}) = Grain output (kg ha^{-1}) / Energy input (MJ ha^{-1})]. Specific energy (SE) denoted the ratio of energy input and grain yield of the crop [SE (MJ kg^{-1}) = Energy input (MJ ha^{-1}) / Grain output (kg ha^{-1})]. Net Energy (NE) depicted the difference between removed energy output and total energy input [NE = Energy output (MJ ha^{-1}) – Energy input (MJ ha^{-1})].

The randomized complete block design with three replications was employed for data analyses. All statistical analyses were performed by the procedure as described by Cochran & Cox (1957). The comparisons were made at 5% level of significance. Correlation studies were carried out using SPSS Software.

The various yield attributes were recorded at both Bathinda and Ludhiana (Tables 2 and 3). The application of liquid microbial inoculants significantly influenced the emergence count at both locations. The maximum emergence count was recorded in treatment T_9: RDF + *B. seminalis* + *S. maltophilia* (50.67 and 50.00 m^{-2}) at Bathinda and Ludhiana, respectively. It was recorded that treatment T_9, T_{11}, T_{10}, T_7, T_6, T_8, T_4 and T_3 showed significant improvement in emergence count at Bathinda and T_9, T_{11}, T_{10}, T_7, T_6, T_8 and T_4 at Ludhiana with respect to T_1. However, plant height was non-significantly ameliorated at both locations. Maximum plant height was achieved by treatment T_9 (261.28 and 220.50 cm), followed by T_{11} (259.72 and 215.87 cm) while the minimum was obtained by treatment T_1 (202.13 and 189.67 cm) at Bathinda and Ludhiana, respectively. Treatment T_9 indicated an increase of 29.2% and 16.2% over T_1 at harvest at Bathinda and Ludhiana, respectively.

The liquid microbial inoculants influenced the number of leaves in forage pearl millet significantly at both

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

Particulars	Units	Equivalent energy (MJ)	References
Input			
Human labor	Man-hour	1.96	Singh and Mittal (1992)
Diesel	litre	56.31	
Electricity	KWh	11.93	
Fertilizer-N	kg	60.60	
Fertilizer-P_2O_5	kg	11.10	
Biofertilizer	kg or litre	2.98	Mihov *et al.* (2012)
Herbicides	kg	238.0	Singh *et al.* (2017)
Insecticides	kg	199.0	
Fungicides	kg	92.0	
Irrigation	m^3	0.63	
Tractor hours	h	64.80	Panesar and Bhatnagar (1994)
Farm machinery	h	62.70	
Output			
Guar seed	kg	14.7	Singh and Mittal (1992)
Guar dry fodder	kg	12.5	

locations. The highest number of leaves were exhibited by the plants exposed to T_9 (12.83 and 12.83), and the lowest by T_1 (10.42 and 10.33) at Bathinda and Ludhiana, respectively. Treatments T_9, T_{11} and T_{10} were recorded as significant over T_1 whereas T_7, T_6, T_8, T_4, T_3, T_5, T_2 and T_{12} were at par with T_1 at both the locations. The chlorophyll content of the inoculated plant was observed to be numerically greater as compared to the control, but statistically no significant effect was recorded. The maximum amount of chlorophyll content was exhibited by T_9 (2.36 and 2.33 mg/g) and the minimum by T_1 (2.13 and 2.02 mg/g) at Bathinda and Ludhiana, respectively. There was a significant improvement in the leaf stem ratio of forage pearl millet with an application of liquid microbial inoculants at both locations. The leaf stem ratio was highest with treatment T_9 (0.341 and 0.325) and lowest with T_1 (0.204 and 0.216) at Bathinda and Ludhiana, respectively. The exploitation of liquid microbial inoculants recorded significant improvement in leaf breadth at both locations. Maximal leaf breadth was attained by T_9 (4.41 and 3.83 cm), while the minimal was by T_1 (2.92 and 2.76 cm) at Bathinda and Ludhiana, respectively. At Bathinda, a statistically significant improvement in leaf length was observed. The application of all the liquid microbial inoculants showed significant improvement over T_1, while the treatment T_{12} was at par with T_1. There was a non-significant increase in leaf

Table 2. Influence of liquid microbial inoculants on yield and yield attributes of forage pearl millet at Bathinda

Treatments	Emergence count (m^{-2})	Plant height (cm)	Number of leaves per plant	Chlorophyll content (mg/g)	Leaf stem ratio	Leaf breadth (cm)	Leaf length (cm)	Dry matter accumulation per plant (g)	Green fodder yield (q/ha)*	Dry matter yield (q/ha)*
T_1	31.00	202.13	10.42	2.13	0.204	2.92	68.07	66.67	481.82	121.82
T_2	35.00	229.20	11.16	2.15	0.227	3.49	74.75	68.67	493.94	123.94
T_3	40.00	223.92	11.33	2.17	0.243	3.48	77.55	69.67	500.00	124.55
T_4	40.00	227.12	11.38	2.17	0.244	3.68	77.58	70.00	506.06	126.06
T_5	35.83	215.00	11.24	2.16	0.235	3.68	76.92	69.00	496.97	124.24
T_6	42.50	245.52	11.67	2.19	0.300	3.87	79.66	71.00	518.18	126.67
T_7	44.17	256.47	11.75	2.23	0.331	3.72	80.33	73.00	521.21	127.27
T_8	42.50	239.67	11.42	2.18	0.277	3.48	77.62	71.00	512.12	126.52
T_9	50.67	261.28	12.83	2.36	0.341	4.41	83.00	77.33	530.30	130.30
T_{10}	47.50	257.00	12.00	2.25	0.332	4.10	80.43	73.67	524.24	129.70
T_{11}	50.00	259.72	12.63	2.26	0.340	4.27	80.71	76.33	527.27	130.00
T_{12}	33.33	224.47	10.63	2.13	0.218	3.44	72.22	68.33	487.88	122.73
CD ($p < 0.05$)	6.45	NS	1.37	NS	0.060	0.82	6.26	NS	NS	NS

*10 quintals (q) = 1 ton

Table 3. Influence of liquid microbial inoculants on yield and yield attributes of forage pearl millet at Ludhiana

Treatments	Emergence count (m^{-2})	Plant height (cm)	Number of leaves per plant	Chlorophyll content (mg/g)	Leaf stem ratio	Leaf breadth (cm)	Leaf length (cm)	Dry matter accumulation per plant (g)	Green fodder yield (q/ha)*	Dry matter yield (q/ha)*
T_1	26.83	189.67	10.33	2.02	0.216	2.76	67.07	69.67	383.94	95.91
T_2	32.00	201.33	10.55	2.10	0.228	2.83	72.00	66.33	390.91	98.48
T_3	34.33	207.60	10.66	2.14	0.236	3.29	70.22	68.67	399.70	100.30
T_4	37.33	207.92	10.72	2.17	0.243	3.33	70.51	69.33	403.03	102.73
T_5	33.50	205.00	10.59	2.11	0.225	3.07	70.09	67.67	391.82	98.79
T_6	41.67	209.58	10.95	2.18	0.271	3.38	74.67	69.67	426.36	106.67
T_7	42.50	211.45	11.63	2.20	0.277	3.46	72.05	70.00	433.94	107.12
T_8	39.67	208.70	10.74	2.17	0.258	3.38	70.76	69.67	408.79	104.70
T_9	50.00	220.50	12.83	2.33	0.325	3.83	76.21	74.23	448.18	108.79
T_{10}	44.17	212.50	11.95	2.22	0.284	3.51	75.12	71.67	435.46	107.39
T_{11}	46.67	215.87	12.33	2.25	0.315	3.55	75.18	73.53	440.91	108.03
T_{12}	29.33	197.33	10.37	2.09	0.221	2.78	68.78	64.17	390.00	96.97
CD ($p < 0.05$)	8.23	NS	1.33	NS	0.061	0.39	NS	6.18	NS	NS

*10 quintals (q) = 1 ton

length at Ludhiana; however, numeric enhancement with respect to control was recorded with the application of microbial inoculants. Liquid microbial inoculants showed non-significant improvement in dry matter accumulation at Bathinda, while a significant increase was observed in Ludhiana. However, numeric enhancement in dry matter accumulation per plant was noted with an application of all the liquid microbial inoculants. Maximum dry matter accumulation per plant was recorded with treatment T_9 (77.33 and 74.23 g) at Bathinda and Ludhiana, respectively. The green fodder yield of forage pearl millet increased non-significantly through the application of liquid microbial inoculants over control at both locations. The maximum yield was obtained by treatment T_9 (530.30 and 448.18 q/ha) and the minimum by T_1 (481.82 and 383.94 q/ha) at Bathinda and Ludhiana, respectively. Improvement in green fodder yield was observed with the use of liquid microbial inoculants, irrespective of treatment applied over T_1. The influence of inoculation of seeds with liquid microbial inoculants on dry matter yield was statistically non-significant. However, numeric enhancement in dry matter yield of forage pearl millet at both locations was observed. The maximum dry matter yield was obtained by application of T_9 treatment (130.30 and 108.79 q/ha), which was followed by treatment T_{11} (130.00 and 108.03 q/ha) at Bathinda and Ludhiana, respectively. The increase in growth and yield attributes of forage pearl millet could be attributed to the integrated influence of nitrogen fixation, phosphate solubilization and production of phytohormones by the inoculated liquid microbial inoculants. Forage yield is a cumulative function of yield components and agronomic characteristics. In addition, nutrient cycling, decomposition of organic matter and improvement of soil health are some of the major activities of bio-inoculants. Further, improvement in the uptake of plant nutrients probably empowered the inoculated plants to manufacture more quantity of photosynthates leading to improvement in dry matter yield. On the same lines, El-Naggar (2010) reported an improvement in leaf characteristics (number of leaves/plant, leaf length and width, leaves fresh and dry weight, flowering parameters, root dry weight, total chlorophyll and mineral content of leaves (N, P and K) of *Narcissus tazetta* L. plants with application of biofertilizers *i.e.* nitrobine (containing *Azotobacter chroococcum* and *Azospirillum barasilense*) and phosphorein (containing phosphate dissolving bacteria) along with organic compost and mineral fertilizer. Kumawat *et al.* (2016) reported that plant height of fodder pearl millet was 189 cm, which was in accordance with the observed results. Similarly, the dry matter yield of fodder pearl millet recorded was consistent with the results of Madankar *et al.* (2023), who also reported similar values. The data on energy analysis were recorded (Table 4). The magnitude of energy input ranged from 5511.3 to 5514.28 MJ ha^{-1}, whereas the magnitude of energy output ranged from 479925 to 662875 MJ ha^{-1}. The highest energy

Table 4. Impact of liquid microbial inoculants on energetics of pearl millet

Treatments	Energy input (MJ ha^{-1})	Energy output (MJ ha^{-1})		Energy productivity (kg MJ^{-1})		Specific energy (MJ kg^{-1})		Energy use efficiency (%)		Net energy (MJ ha^{-1})	
		Bathinda	Ludhiana	Bathinda	Ludhiana	Bathinda	Ludhiana	Bathinda	Ludhiana	Bathinda	Ludhiana
T_1	5511.30^{b}	602275^{f}	479925	8.74	6.96	0.114	0.143	109.28	87.08	596763.70	474413
T_2	5514.28^{a}	617425^{def}	488637	8.95	7.08	0.111	0.141	111.96	88.61	611910.70	483123
T_3	5514.28^{a}	625000^{cdef}	499625	9.06	7.24	0.110	0.137	113.34	90.60	619485.70	494110
T_4	5514.28^{a}	632575^{bcde}	503787	9.17	7.30	0.108	0.136	114.71	91.36	627060.70	498273
T_5	5514.28^{a}	621212^{def}	489775	9.01	7.10	0.110	0.140	112.65	88.81	615698.20	484260
T_6	5514.28^{a}	647725^{abcd}	532950	9.39	7.73	0.106	0.129	117.46	96.64	642210.70	527435
T_7	5514.28^{a}	651512^{abc}	542425	9.45	7.86	0.105	0.127	118.15	98.36	645998.20	536910
T_8	5514.28^{a}	640150^{abcd}	510987	9.28	7.41	0.107	0.134	116.08	92.66	634635.70	505473
T_9	5514.28^{a}	662875^{a}	560225	9.61	8.12	0.103	0.123	120.21	101.59	657360.70	554710
T_{10}	5514.28^{a}	655300^{ab}	544325	9.50	7.89	0.105	0.126	118.83	98.71	649785.70	538810
T_{11}	5514.28^{a}	659087^{ab}	551137	9.56	7.99	0.104	0.125	119.52	99.94	653573.20	545623
T_{12}	5514.28^{a}	609850^{ef}	487500	8.84	7.07	0.113	0.141	110.59	88.40	604335.70	481985

The values of experiment are means of three replications ± standard error; Means with the same letter down the column are not significantly different based on Duncan's multiple range test ($p \leq 0.05$) n = 3, a>b>c.

output was obtained with T_9 treatment at Bathinda and Ludhiana, respectively. The lowest energy output was noted with treatment devoid of liquid microbial inoculants (T_1). Similarly, treatment T_9 recorded the highest energy productivity (9.61 and 8.12 kg MJ^{-1}) and energy use efficiency (120.21 and 101.59) at Bathinda and Ludhiana, respectively, compared to other treatments. However, all the inoculated treatments were greater in energy productivity and energy use efficiency when compared to the sole use of chemical fertilization (T_1). Specific energy showed the opposite trend. Specific energy indicates the amount of energy used to produce one unit of grain. Specific energy was highest in treatment T_1 and T_{12} at both locations. The minimum specific energy was recorded in the treatment T_9 system, where the maximum amount of energy productivity was obtained. The net energy was maximum in treatment T_9 followed by T_{11} at both locations due to higher differences between energy output removed and total input energy used. Indeed, all the energy parameters were found to be higher in inoculated treatments as compared to control. This is probably attributed to the increased green fodder yield and dry matter yield in the aforesaid treatment due to efficient utilization of the applied nutrients by inoculated microbes as these play a significant role in phosphate solubilization and biological nitrogen fixation. Likewise, phytohormones produced by inoculated bacteria improved the root morphology for better absorption of nutrients from the deeper layers of soil.

Liquid microbial inoculants of *Azotobacter* sp., *Sphingobacterium* sp., *S. maltophilia* and *B. seminalis* either alone or in various combinations along with recommended dose of fertilizer improved the productivity and energetics of forage pearl millet. Nonetheless, the treatment T_9: RDF + *B. seminalis* + *S. maltophilia* was observed to be the most superior. Thus, these microbial inoculants if applied consistently for a prolonged duration, could play an essential role in ameliorating the productivity of forage pearl millet with simultaneous improvement in the energy produced and thus, consequently increasing the animal productivity.

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