Integrated use of moringa and soil applied press mud proved a smart agricultural practice for improving anti-oxidant defense mechanism, nitrogen and water efficiency in rainfed Panicum miliaceum crop

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Abstract

Pros-millet is emerging as a tolerant crop to marginal agricultural system with limited natural resources, but unfortunately, due to short growing period under soil nitrogen deficit condition become the challenge for proso-millet cultivating community. For this, field trials were conducted on the moringa applications with the addition of various soil organic press mud treatments at the Experimental Research Farm-BZU, Pakistan during the summer growing seasons (2022, 2023). The combine effect of applied moringa via bio-priming + moringa spray resulted the significantly higher values in yield related attributes {fodder yield (28.54%), total biological yield (22.19%)} under the soil applied urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) during the year-II than year-I. Bio-priming + moringa spray treatment improved the anti-oxidants status by enhancing water use efficiency (3.36%), and nitrogen use efficiency (0.78%) in the proso-millets plants during the soil applied treatment of urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}). The notable economic outcome was received in the applied treatments bio-priming + moringa spray urea (22.5 kg ha-1) + press mud (2500 kg ha^{-1}) for proso-millet production in terms of a cut above net income (258.14 US$ ha^{-1}) and benefit cost ratio (1.59). This project study prominently noted that proso-millet crop can be cultivated for grain and fodder purposes with the treatment applied moringa bio-priming plus spray under the use of soil organic nitrogen through urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) in the rainfed regions of Pakistan.

Introduction

Climate change is having a negative influence on the worldwide agricultural efficiency > 20% by affecting the food security, farmers healthy livelihoods and the economic globalization [1]. Arid zone agricultural crops are the most critical pillars of Pakistan's economy and has recorded significantly to its annual contribution of ≥ 17 billion rupees [2]. Recently, the burgeoning population required a higher agricultural commodity in terms of food and feed under arid environmental condition [3]. Higher crop productivity can be possible by using the integrated crop husbandry practices especially by introducing the new, high yielding and tolerant cultivars that may be able to perform under the dryland farming conditions. Therefore, the introduction of new drought-resistant crops may be a solution in the current circumstances of gradual global population growth and water scarcity [4].

Proso-millet is an emerging drought tolerant crop in the region under limited water resources or unpredictable rainfall. It is a fast-maturing cereal crop used for human consumption and livestock feed in arid and semi-arid environments of Pakistan [5]. Its dual characteristics of excellent water use efficiency (WUE) and shallow root system have helped in obtaining the higher grains and biomass production in the drought prone areas affected by diversified climate, soil and varied elevations [6]. Nitrogen use efficiency (NUE) is one of the major factors for proso-millet cultivation, in both grains and forage production. The source and amount of N application depends on the experimental field trials climatic, and soil conditions for producing the higher aerial biomass, dry matter production, and forage production [7]. Nitrogen fertilizers are used in three split steps as top dressing of the soil during the crop phenological growth stages [8]. Proso-millet crop has a variety of desirable agronomic features, especially having a short duration of growing period, better NUE-WUE requirements, and excellent survival capacity under environmental stresses like salt, water, temperature etc [9].

The mechanism of aerobic metabolism resulted in the formation of inevitable reactive oxygen species (ROS) and protective anti-oxidant contents during the photosynthesis and respiration phases in proso-millet crop under unfavorable conditions [10]. The plants are exposed to disruption of homeostasis, resulting in cellular oxidative damage through excessive release of ROS under unfavorable environmental conditions [11]. The production of ROS is signaling molecules that act as secondary messengers, and balance the hormonal production to activate the defensive system by producing higher anti-oxidants contents or oxidative cell destruction by over-generation of ROS species [12]. The positive behavior of anti-oxidants including’s total soluble proteins (TSP), superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), ascorbic acid (AsA), and total phenolic contents (TPC) may have potential to improve the tolerance by scavenging ROS activities after the exogenous applications of organic stimulators [13].

The potential use of moringa oleifera extract (MLE_{30}) is gaining popularity recently as a naturally occurring biostimulator to improve crop drought tolerance in arid and semi-arid environments [14]. Observations proved that the application of this MLE_{30} extract can be used via seed priming well-known as biopriming and foliar methods in the cereal crop like proso-millet but the synergistic method (Biopriming + Moringa spray) may have significant results in increasing the rapid germination, plant height, tillers production, leaves emergence, panicle formation, and neutralized the ROS activities by boosting-up the anti-oxidants level [15]. Moreover, MLE_{30} contains a rich source of plant hormones like Zeatin which improves water use efficiency (WUE) by protecting against water loss through transpiration, and also develops a better root system for effective nitrogen use efficiency (NUE) in the crops [16]. The efficiency of moringa use can be increased by additional use of organic sources of soil nitrogen as a soil conditioner for improving soil profile during the cultivation of proso-millet crop [17].

The application nitrogen (N) fertilizer is the most critical and essential component for producing the quantity and quality of grains production of proso-millet crop under the limited soil-plant-available nitrogen [18]. In this context, N application method is one of the main factors in the agronomic management of crops using the organic or inorganic sources. Sugarcane press mud is a natural occurring soil organic fertilizer (a rich source of NPK) that improves soil-plant-water relations [19]. According to author’s best review, there is dire need to conduct the research project to check the synergistic application of synthetic nitrogen (urea) and organic (press mud) for cultivation of proso-millet grains and fodder production under the arid and semi-arid environment. Therefore, field studies were designed to investigate the use of various soil nitrogen application methods with different moringa treatments on the morphological, yield related attributes and anti-oxidants status of proso-millet plants.

Materials and methods

SANJHI an organic bio-stimulant

The organic plant growth enhancer well-known as SANJHI is prepared from moringa trees (*Moringa oleifera*). For this, fresh moringa leaves were harvested and collected early in the morning (at 11:00 am) from an established moringa garden located at the Experimental Research Farm, Institute of Agronomy, Faculty of Agricultural Sciences & Technology (FAS&T), Bahauddin Zakariya University (BZU), Multan, Pakistan. Selected leaves were dried by spreading freely at room temperature in the laboratory for 6 hours and then stored in polythene bags for 74 hours in a laboratory chiller (at temperature – 80°C). A manual extractor machine was used to crush the frozen leaves, it was purified in a digital centrifuge machine (at 25°C at 9000 rpm for 25 minutes) and used for seed treatment / foliar application by diluting with distilled water at the ratio 1:30 named as moringa leaves extract (MLE_{30}).

Press mud an organic fertilizer

The required press mud was purchased from Fatima Sugar Mills, Muzaffargarh, South Punjab, Pakistan as per experimental treatments. The chemical analysis of press mud was performed at Department of Soil Science, Faculty of Agricultural Sciences & Technology (FAS&T), Bahauddin Zakariya University (BZU), Multan, Pakistan. Observations illustrated the characteristics of press mud having color darkest brown, sponge, soft, muddy in texture (N 0.45%, P 0.43 mg g^{-1}, K 1.30 mg g^{-1}).

Soil physico-chemical analysis

Soil samples with a surface density of 0–25 cm were taken from 3 different sites in the field experimental research area. The samples were dried in the laboratory at room temperature, then gently grinded and mixed through a 2.5 cm sieve. All the analysis were performed at Department of Soil Science, Faculty of Agricultural Sciences & Technology (FAS&T), Bahauddin Zakariya University (BZU), Multan, Pakistan by following the standard protocols [20] given in USDA Handbook No. 60 presented in the Table 1. Meteorological data presented the temperature, humidity, and rainfall values during phenological crop growth stages of proso-millet crop production (Fig. 1).

Table 1
Soil analysis of Agronomic Experimental Research Area, BZU, Multan, Pakistan

Field soil components	2022	2023
Soil physical analysis		
Sand	23.02%	23.01%
Silt	59.03%	59.04%
Clay	19.05%	19.08%
Soil Texture	Silty clay loam	
Soil chemical analysis		
Soil Organic matter	0.62%	0.79%
Saturation percentage	38.22%	38.33%
Total Nitrogen percentage	0.07%	0.09%
Phosphorus	4.90 ppm	6.98 ppm
Potassium	304.11 ppm	304.22 ppm
EC	3.33 dS m^{-1}	3.44 dS m^{-1}
pH	7.82	7.99
Zinc	0.38 ppm	0.40 ppm
$CaCO_3$	9.13%	9.22%

Experimental layout

2 years of field studies were conducted with following treatments as, factor A: Moringa bio-stimulant (MLE_{30} moringa leaf extract) included: Control (Dry seeds), Hydro primed, (Distilled water), Moringa Bio-priming [21], Moringa spray [17], Bio-priming + Moringa spray, factor B: Soil organic nitrogen included; Urea (45 kg ha^{-1}) [22], Press mud (10000 kg ha^{-1}) [23], Urea (11.25 kg ha^{-1}) + Press mud (5000 kg ha^{-1}), Urea (22.5 kg ha^{-1}) + Press mud (2500 kg ha^{-1}), Urea (33.75 kg ha^{-1}) + Press mud (1000 kg ha^{-1}). Soil fertilization treatment with organic nitrogen was added during soil preparation in the mentioned experimental unit. Proso-millet seeds were treated using the seed priming method in a ratio of 1:5 for 6 hours under the aerated environment via digital aquarium machine [14]. Distilled water was used for hydro-priming, and bio-priming was performed using SANJHI solution in a ratio of 1:30 (MLE_{30}: Water). Two foliar of moringa spray was applied at the vegetative (tillers formation) and reproductive (grains formation) growth stages of proso-millet crop respectively.

Agronomic crop management practices

The research was conducted in the summer season of 2022, 2023 at the Experimental Research Farm, Institute of Agronomy, Faculty of Agricultural Sciences & Technology (FAS&T), Bahauddin Zakariya University (BZU), Multan, Pakistan. A randomized complete block design (RCBD) was used with a two-way factorial design with three replications. The recommended seed rate for proso-millet-P26 crop was 10 kg ha^{-1}. The area of each experimental unit was 3 × 5 m^2 with keeping the uniform distance of row-row at 30 cm and plant-plant at 10 cm. Pre-irrigation was applied before sowing the proso-millet crop at 10 cm depth for achieving the 100% soil field capacity followed by 2 ploughing and planking. Three recommended irrigations were irrigated in critical stages of growth: tillering, heading, seed development of proso-millet crop by following the BBC scale (code 25, 55, 80) [24]. In both years of the study, planting and harvesting dates were July 15 and October 25, respectively. All the agronomic plant protection measurements were adapted to the needs of a crop.

Recorded observations

Anti-oxidant contents

Fresh flag leaves were collected from different three healthy plants in treated experimental units in the morning time at 09:00 am (25 ± 5°C) after the last applied irrigation and kept in the laboratory chiller at -80°C for 72 hours. The labeled leaves were crushed into a paste in a mortar by adding the prepared buffer solution (1 mL, pH 7.2). For protein extraction, the prepared buffer solution was mixed with 1 µM protease inhibitor. The required phosphate buffer solution (PBS) was synthesized by adding Na_2HPO_4 (10 mM), KH_2PO_4 (2 mM), KCl (2.7 mM), and NaCl (1.37 mM) followed by gradual mixing of HCl to obtain the buffer pH at 7.2. In the meantime, the samples were purified into a supernatant solution using the digital centrifuge machine (adjusting the resolution at 25, 000 rpm for 2 minutes). The standard curve was prepared on excel sheet by mixing the Dye stock (400 µL) in Bovine serum albumin (BSA) through distilled water at different concentrations (10, 20, 30, 40, and 50 µg mL^{-1}). On the other-hand, samples were mixed carefully via digital vortex mixer and stored in the incubator (for 30 minutes) at laboratory temperature. Total soluble proteins (TSP) were calculated at 595 nm wavelength as per protocol described by [25] in the digital nano-spectrophotometer. The protocols described by [26] were used to determine the peroxidase (POD), catalase (CAT), superoxide dismutase (SOD), ascorbic acid (AsA) by [27] and total phenolic contents (TPC) by [28].

Agronomic water use efficiency (WUE)

The protocol was followed by [6] to calculate the agronomic water use efficiency (WUE). The given formula illustrated the total dry matter yield and grains production divided by total evapo-transpiration;

$$\text{Agronomic Water Use Efficiency (WUE)} = \{(Y_i - Y_d) / I_i\}$$

Formula described the abbreviation as;

Y_i = {Total mass production noted after water irrigations during the project study unit (i^{th})}

Y_d = {Total mass production noted after average rainfall observed during project study (i^{th})}

I_i = {Depth of water irrigation during the project study}

Agronomic nitrogen use efficiency (NUE)

[29] described the protocol to measure the agronomic nitrogen use efficiency (NUE). The given formula demonstrated the observed total grains yield divided by nitrogen application during the project study;

$$\text{Agronomic Nitrogen Use Efficiency (NUE)} = \{(Y_i - Y_c) / N_i\}$$

Formula described the abbreviation as;

Y_i = {Total grains production observed in i^{th} treatment}

Y_c = {Total grains production in control}

N_i = {Nitrogen application in i^{th} treatment}

Chlorophyll contents

[30] illustrated the protocol to estimate the chlorophyll contents (*a*, *b*). For this, plant leaves sample (100 mg) was mixed with acetone (20 mL 80% v/v) and crushed into paste in the mortar. Following formulas were given below;

Chlorophyll *a* (mg g^{-1}) = {12.7 (A663) – 2.69 (645)} × V / (1000 × W)
Chlorophyll *b* (mg g^{-1}) = {22.9 (A645) – 4.68 (663)} × V / (1000 × W)

All the morphological growth-related attributes, development parameters and yield components were observed according to the recommended protocols.

Benefit cost ratio (BCR)

Economic analysis of proso-millet crop production elaborated the total expenditures, gross income, net income and BCR during the average both years (2022, 2023) of the project experimental studies. Total expenditures consisted of charges including's land, soil preparation, seed, press mud application, sowing methods, nitrogen fertilizers, water irrigations, agronomic plant protection measures, harvesting, storage, and value chain products. Gross income was calculated as per market rate (in dollars) of the proso-millet grains and fodders. [31] proposed the formula to determine the net income and BCR as given below;

Net income = {Gross income – Total expenditure}

Benefit cost ratio (BCR) = {Gross income / Total expenditure}

Pearson correlation analysis

Correlation relationship analysis was performed by using Statistix 8.1 software among the observed morphological growth & development parameters, yield components, anti-oxidant contents, and physiological attributes of proso-millet crop cultivation during the average both years of trials [32].

Statistical analysis

Statistix 8.1 software was used for Fisher's analysis of variance. The treatments means were compared at 5% probability level by using the Duncan's multiple range test [33]. All the graphs and tables were prepared in Microsoft office 2019.

Results

Proso-millet morphological growth attributes

All the morphological growth characteristics in proso-millet plants performed significantly different due to the use of moringa under soil organic nitrogen during the years 2022 and 2023 shown in Table 2. Plants treated with moringa application via bio-priming + moringa spray method obtained maximum plant height, number of leaves plant^{-1}, numbers of tillers plant^{-1} during the additional use of soil organic nitrogen via urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) (Table 2). And minimum values were observed in the applied treatments as single factors of hydro primed, moringa Bio-priming, moringa spray under urea (45 kg ha^{-1}) followed by press mud (10000 kg ha^{-1}), urea (11.25 kg ha^{-1}) + press mud (5000 kg ha^{-1}), urea (33.75 kg ha^{-1}) + press mud (1000 kg ha^{-1}) respectively (Table 2). A significant year's interaction was noted in term of moringa applications along-with various soil organic nitrogen doses and showed greater results in 1st years than 2nd year of the experimental trials (Table 2). Data revealed that combine use of bio-priming plus foliar spray for moringa application recorded highest values in the length of panicle, panicle weight under applied soil organic nitrogen via urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) during the trials 2022 and 2023 (Table 2). The promotion of growth increasing trend was obtained after the combine use of moringa and press mud applications as compared to single factor as bio-priming, hydro primed, moringa spray under applied single dose of urea (45 kg ha^{-1}) followed by press mud (10000 kg ha^{-1}) in the both experimental trials year-I & Year-II presented in Table 2.

Table 2
Evaluation of moringa priming with press mud application on the morphological growth parameters of proso-millet crop

	2022					**2023**				
Soil organic nitrogen application / Moringa application	**Control**	**Hydro primed**	**Moringa Bio-priming**	**Moringa spray**	**Bio-priming + Moringa spray**	**Control**	**Hydro primed**	**Moringa Bio-priming**	**Moringa spray**	**Bio-priming + Moringa spray**
Plant height (cm)										
Urea (45 kg ha⁻¹)	98.22i ± 0.65	101.62g ± 0.77	108.07d ± 0.86	107.10de ± 0.63	113.68b ± 0.94	99.14i ± 0.65	103.86gh ± 0.83	109.32de ± 0.64	107.97ef ± 0.84	114.64c ± 0.90
Press mud (10000 kg ha⁻¹)	95.73j ± 0.86	100.77gh ± 0.80	105.46ef ± 1.05	110.90c ± 0.95	114.76b ± 0.91	101.49hi ± 0.70	105.98fg ± 0.79	110.39de ± 0.85	115.50c ± 1.02	119.56b ± 0.81
Urea (11.25 kg ha⁻¹) + Press mud (5000 kg ha⁻¹)	77.32p ± 0.58	81.83no ± 0.50	86.74m ± 0.61	90.92l ± 0.76	98.91hi ± 0.69	81.76m ± 0.25	87.53l ± 0.43	91.25k ± 0.65	96.24j ± 0.74	102.41h ± 0.63
Urea (22.5 kg ha⁻¹) + Press mud (2500 kg ha⁻¹)	100.96gh ± 0.57	104.15f ± 0.70	108.28d ± 0.76	114.13b ± 0.99	120.25a ± 0.72	103.18h ± 0.55	109.21de ± 0.62	111.70d ± 0.73	118.28b ± 0.84	129.49a ± 0.71
Urea (33.75 kg ha⁻¹) + Press mud (1000 kg ha⁻¹)	80.15o ± 0.87	83.35n ± 0.39	89.31l ± 0.63	93.41k ± 0.79	98.96hi ± 0.60	82.15m ± 0.64	86.06l ± 0.25	90.74k ± 0.70	96.31j ± 1.42	101.17hi ± 0.42
	99.40B					103.01A				
	LSD@0.05 {Year-2022 ± 2.1308, Year-2023 ± 2.7470, Year Interaction ± 0.4865}									
Number of leaves plant⁻¹										
Urea (45 kg ha⁻¹)	6.36ij ± 0.18	6.72g.j ± 0.06	8.80de ± 0.24	9.65cd ± 0.11	10.83b ± 0.32	7.73i.k ± 0.14	8.92ef ± 0.10	9.41de ± 0.12	11.09c ± 0.03	11.59bc ± 0.24
Press mud (10000 kg ha⁻¹)	6.27ij ± 0.14	5.72j.l ± 0.10	7.51f.h ± 0.13	7.75fg ± 0.06	10.31bc ± 0.13	8.23g.i ± 0.13	9.42de ± 0.13	9.93d ± 0.15	11.26bc ± 0.06	11.71b ± 0.39
Urea (11.25 kg ha⁻¹) + Press mud (5000 kg ha⁻¹)	5.68j.l ± 0.15	4.78l ± 0.24	4.95kl ± 0.29	5.16kl ± 0.19	5.84i.k ± 0.15	7.03l ± 0.13	7.32kl ± 0.11	7.29kl ± 0.12	7.83h.k ± 0.04	8.33gh ± 0.18
Urea (22.5 kg ha⁻¹) + Press mud (2500 kg ha⁻¹)	7.59f.h ± 0.18	7.80ef ± 0.23	9.44cd ± 0.17	9.94bc ± 0.27	12.53a ± 0.24	7.95h.j ± 0.12	9.16ef ± 0.12	9.85d ± 0.14	11.40bc ± 0.04	13.26a ± 0.22
Urea (33.75 kg ha⁻¹) + Press mud (1000 kg ha⁻¹)	7.48f.h ± 0.17	6.56h.j ± 0.12	7.83ef ± 0.10	6.79f.i ± 0.09	7.51f.h ± 0.38	7.10l ± 0.10	7.30kl ± 0.12	7.55j.l ± 0.11	7.94h.j ± 0.11	8.67fg ± 0.14
	7.59B					9.09A				
	LSD@0.05 {Year-2022 ± 1.0407, Year-2023 ± 0.5895, Year Interaction ± 0.1728}									
Number of tillers plant⁻¹										
Urea (45 kg ha⁻¹)	3.39i.k ± 0.07	4.57d.f ± 0.05	4.22fg ± 0.20	4.74c.e ± 0.06	4.45ef ± 0.01	5.77g.i ± 0.08	5.95e.g ± 0.02	6.28bc ± 0.03	5.98e.g ± 0.06	6.23b.d ± 0.06
Different letters represent the level of significant among treatment means at probability level @ 5%										

	2022					2023				
Soil organic nitrogen application / Moringa application	**Control**	**Hydro primed**	**Moringa Bio-priming**	**Moringa spray**	**Bio-priming + Moringa spray**	**Control**	**Hydro primed**	**Moringa Bio-priming**	**Moringa spray**	**Bio-priming + Moringa spray**
Press mud (10000 kg ha^{-1})	3.58h.j ± 0.06	3.55h.k ± 0.20	3.32i.k ± 0.15	3.63h.j ± 0.01	3.75g.i ± 0.11	5.69h.j ± 0.04	5.50jk ± 0.01	5.59i.k ± 0.02	5.69h.j ± 0.04	5.77g.i ± 0.06
Urea (11.25 kg ha^{-1}) + Press mud (5000 kg ha^{-1})	3.95gh ± 0.05	4.89c.e ± 0.08	4.21fg ± 0.06	4.99cd ± 0.01	4.51ef ± 0.05	5.70h.j ± 0.02	5. 38k ± 0.03	5.69h.j ± 0.04	5.51jk ± 0.01	5.84f.h ± 0.04
Urea (22.5 kg ha^{-1}) + Press mud (2500 kg ha^{-1})	4.91c.e ± 0.06	5.06bc ± 0.06	5.46b ± 0.07	5.51b ± 0.02	6.10a ± 0.09	6.13c.e ± 0.03	6.04d.f ± 0.11	5.99e.g ± 0.04	5.98e.g ± 0.03	6.66a ± 0.03
Urea (33.75 kg ha^{-1}) + Press mud (1000 kg ha^{-1})	3.10k ± 0.06	3.49h.k ± 0.05	3.21jk ± 0.05	3.93gh ± 0.04	4.19fg ± 0.10	6.39b ± 0.04	6.13c.e ± 0.05	6.31bc ± 0.02	6.26b.d ± 0.01	6.31bc ± 0.02
	4.27B					5.95A				
	LSD@0.05 {Year-2022 ± 0.4720, Year-2023 ± 0.2259, Year Interaction ± 0.0751}									
Length of panicle (cm)										
Urea (45 kg ha^{-1})	19.05f ± 0.02	19.72e ± 0.03	19.83e ± 0.03	20.55d ± 0.03	20.92d ± 0.02	19.26j ± 0.02	20.16h ± 0.02	19.76i ± 0.02	21.16g ± 0.05	22.09e ± 0.11
Press mud (10000 kg ha^{-1})	15.81j.l ± 0.01	16.29ij ± 0.02	17.80g ± 0.04	18.28g ± 0.26	18.93f ± 0.18	16.16n ± 0.06	17.56l ± 0.01	17.58l ± 0.02	21.18g ± 0.03	21.84ef ± 0.09
Urea (11.25 kg ha^{-1}) + Press mud (5000 kg ha^{-1})	15.36l ± 0.03	15.75kl ± 0.01	16.11i.k ± 0.03	16.51hi ± 0.13	17.00h ± 0.03	15.44o ± 0.03	16.09n ± 0.02	15.96n ± 0.03	17.42l ± 0.04	18.43k ± 0.08
Urea (22.5 kg ha^{-1}) + Press mud (2500 kg ha^{-1})	20.74d ± 0.01	20.94d ± 0.02	22.28c ± 0.03	22.98b ± 0.18	23.76a ± 0.18	21.71f ± 0.06	22.74z ± 0.04	23.23c ± 0.09	24.61b ± 0.01	26.12a ± 0.11
Urea (33.75 kg ha^{-1}) + Press mud (1000 kg ha^{-1})	12.78o ± 0.03	11.57p ± 0.02	13.21no ± 0.04	13.65n ± 0.03	14.35m ± 0.03	13.06q ± 0.03	13.50p ± 0.01	13.74p ± 0.03	16.92m ± 0.03	18.16k ± 0.06
	17.77B					18.95A				
	LSD@0.05 {Year-2022 ± 0.5065, Year-2023 ± 0.2958, Year Interaction ± 0.0861}									
Panicle weight (g)										
Urea (45 kg ha^{-1})	21.19j ± 0.06	22.16hi ± 0.10	23.30ef ± 0.08	25.20d ± 0.07	26.57c ± 0.20	18.42n ± 0.08	19.59mn ± 0.03	20.46lm ± 0.23	21.99jk ± 0.12	23.98f.i ± 0.44
Press mud (10000 kg ha^{-1})	19.81lm ± 0.08	20.84jk ± 0.09	21.87i ± 0.05	23.87e ± 0.06	27.86b ± 0.22	22.82h.k ± 0.04	24.31f.h ± 0.04	25.03ef ± 0.92	27.73cd ± 0.06	29.35b ± 0.14
Urea (11.25 kg ha^{-1}) + Press mud	18.31op ± 0.09	19.36mn ± 0.06	20.27kl ± 0.05	22.38g.i ± 0.07	23.80e ± 0.23	22.75i.k ± 0.08	22.67i.k ± 0.01	24.39fg ± 0.24	19.37mn ± 0.08	27.00d ± 0.15
Different letters represent the level of significant among treatment means at probability level @ 5%										

	2022					2023				
Soil organic nitrogen application / Moringa application	**Control**	**Hydro primed**	**Moringa Bio-priming**	**Moringa spray**	**Bio-priming + Moringa spray**	**Control**	**Hydro primed**	**Moringa Bio-priming**	**Moringa spray**	**Bio-priming + Moringa spray**
(5000 kg ha^{-1})										
Urea (22.5 kg ha^{-1}) + Press mud (2500 kg ha^{-1})	21.08j ± 0.11	22.50gh ± 0.09	22.98fg ± 0.09	25.14d ± 0.09	28.79a ± 0.20	26.31de ± 0.09	26.78d ± 0.01	29.02bc ± 0.22	29.69b ± 0.07	34.15a ± 0.21
Urea (33.75 kg ha^{-1}) + Press mud (1000 kg ha^{-1})	17.99p ± 0.06	18.89no ± 0.06	19.75lm ± 0.07	21.99hi ± 0.05	24.78d ± 0.22	23.17g.j ± 0.03	19.54mn ± 0.04	18.13n ± 0.21	21.53kl ± 0.08	24.01f.i ± 0.30
	22.43B					24.09A				
	LSD@0.05 {Year-2022 ± 0.6224, Year-2023 ± 1.4969, Year Interaction ± 0.2277}									
Different letters represent the level of significant among treatment means at probability level @ 5%										

Proso-millet morphological yield and yield related attributes

Observations illustrated the different results in yield related attributes of proso-millet crop under different methods of moringa application under various soil organic nitrogen doses (Table 3). Plants having treatments with bio-priming + moringa spray performed better in grains panicle^{-1} and 1000 grains weight under applied dose of urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) as compared to lowest in the treatments of control (dry seeds) and hydro-primed under urea (45 kg ha^{-1}) and press mud (10000 kg ha^{-1}) applications during the field experimental conditions (2022 and 2023) shown in Table 3. Observations highlighted the positively higher results in the values of aerial biomass yield, grain's yield, fodder yield and total biological yield after application of treatment moringa application especially by using the biopriming + moringa spray methods as compared to others under the urea (45 kg ha^{-1}) and press mud (10000 kg ha^{-1}) soil dose during the project study of both years (Year-I & Year-II) (Table 3). The interactive effect of applied treatments of moringa with soil organic nitrogen applications on harvest index (HI) was obtained significant. Table 3 demonstrated that moringa spray treatment resulted maximum HI under applied dose of urea (33.75 kg ha^{-1}) + press mud (1000 kg ha^{-1}) followed by urea (45 kg ha^{-1}) and press mud (10000 kg ha^{-1}) as compared to other treatments. Year interaction for all yield related attributes was noted significantly greater in 2nd year than 1st year of the experiments (Table 3).

Table 3
Evaluation of moringa priming with press mud application on the morphological yield and yield related parameters of proso-millet crop

	2022					2023				
Soil organic nitrogen application / Moringa application	**Control**	**Hydro primed**	**Moringa Bio-priming**	**Moringa spray**	**Bio-priming + Moringa spray**	**Control**	**Hydro primed**	**Moringa Bio-priming**	**Moringa spray**	**Bio-priming + Moringa spray**
Number of grains $panicle^{-1}$										
Urea (45 kg ha^{-1})	2247.7r ± 0.45	2289.9n ± 0.49	2347.8j ± 0.83	2403.3f ± 0.90	2446.0d ± 0.92	2409.9o ± 0.30	2453.2k ± 0.50	2537.3f ± 1.96	2572.2e ± 0.22	2462.7j ± 0.72
Press mud (10000 kg ha^{-1})	2225.9s ± 0.64	2275.9o ± 0.75	2327.3k ± 0.43	2385.6g ± 0.94	2563.5b ± 0.63	2443.1l ± 0.84	2491.6g ± 0.53	2535.4f ± 0.69	2574.3e ± 0.44	2694.3b ± 0.67
Urea (11.25 kg ha^{-1}) + Press mud (5000 kg ha^{-1})	2218.5t ± 0.71	2266.7p ± 0.71	2320.0l ± 0.09	2383.1g ± 0.64	2423.1e ± 0.73	2428.0m ± 0.47	2479.2i ± 1.18	2590.6d ± 0.62	2652.6c ± 0.72	3215.0a ± 0.72
Urea (22.5 kg ha^{-1}) + Press mud (2500 kg ha^{-1})	2213.7u ± 0.42	2261.2q ± 0.79	2314.2m ± 0.49	2375.9h ± 0.44	3118.7a ± 0.79	2346.8r ± 0.65	2341.5s ± 0.49	2396.4p ± 0.63	2305.6t ± 0.74	2410.8o ± 0.87
Urea (33.75 kg ha^{-1}) + Press mud (1000 kg ha^{-1})	2210.5u ± 1.05	2260.5q ± 2.05	2311.3m ± 0.58	2371.1i ± 0.72	2462.7c ± 0.95	2376.1q ± 0.84	2415.3n ± 0.31	2485.6h ± 0.26	2347.4r ± 0.64	2376.3q ± 0.42
	2361.0B					2493.7A				
	LSD@0.05 {Year-2022 ± 3.5655, Year-2023 ± 4.0540, Year Interaction ± 0.7707}									
1000 grains weight (g)										
Urea (45 kg ha^{-1})	6.59f.h ± 0.02	5.56j.l ± 0.05	5.61j ± 0.08	7.18b.d ± 0.09	7.03c.e ± 0.06	5.55kl ± 0.06	7.25cd ± 0.03	5.93h.k ± 0.05	7.51bc ± 0.06	7.36b.d ± 0.13
Press mud (10000 kg ha^{-1})	6.39gh ± 0.06	6.01i ± 0.03	6.24hi ± 0.06	7.44b ± 0.06	7.35bc ± 0.06	6.01g.k ± 0.02	6.22f.i ± 0.01	6.88de ± 0.01	7.77b ± 0.05	7.67bc ± 0.21
Urea (11.25 kg ha^{-1}) + Press mud (5000 kg ha^{-1})	5.18lm ± 0.09	5.50j.m ± 0.04	5.31j.m ± 0.06	5.33j.m ± 0.07	5.43j.m ± 0.06	4.77m ± 0.09	5.18lm ± 0.05	4.94m ± 0.06	5.17lm ± 0.07	6.11f.j ± 0.10
Urea (22.5 kg ha^{-1}) + Press mud (2500 kg ha^{-1})	7.32bc ± 0.01	6.68e.g ± 0.08	6.83d.f ± 0.06	7.45b ± 0.02	8.55a ± 0.06	6.33f.h ± 0.01	7.59bc ± 0.08	6.59ef ± 0.01	7.50bc ± 0.12	8.60a ± 0.03
Urea (33.75 kg ha^{-1}) + Press mud (1000 kg ha^{-1})	5.28j.m ± 0.07	5.37j.m ± 0.01	5.20k.m ± 0.06	5.15m ± 0.13	5.57jk ± 0.07	5.65j.l ± 0.07	6.45e.g ± 0.01	5.59kl ± 0.05	5.76i.k ± 0.18	6.50e.g ± 0.07
	6.22B					6.43A				
	LSD@0.05 {Year-2022 ± 0.3784, Year-2023 ± 0.4943, Year Interaction ± 0.0861}									
Aerial biomass yield (t ha^{-1})										
Urea (45 kg ha^{-1})	2.10j ± 0.01	2.06jk ± 0.03	2.04j.l ± 0.01	2.15ij ± 0.01	2.24i ± 0.23	2.06l ± 0.11	2.07kl ± 0.01	2.15kl ± 0.03	2.36i.k ± 0.05	2.57h.j ± 0.06
Press mud (10000 kg ha^{-1})	2.93h ± 0.22	3.36de ± 0.01	3.05gh ± 0.03	3.29ef ± 0.04	3.19f ± 0.01	2.99d.f ± 0.21	2.71f.h ± 0.03	3.04de ± 0.09	2.98d.f ± 0.07	3.19c.e ± 0.10

Different letters represent the level of significant among treatment means at probability level @ 5%

	2022					2023				
Soil organic nitrogen application / Moringa application	**Control**	**Hydro primed**	**Moringa Bio-priming**	**Moringa spray**	**Bio-priming + Moringa spray**	**Control**	**Hydro primed**	**Moringa Bio-priming**	**Moringa spray**	**Bio-priming + Moringa spray**
Urea (11.25 kg ha^{-1}) + Press mud (5000 kg ha^{-1})	3.16fg ± 0.11	3.21f ± 0.01	3.22f ± 0.04	3.47cd ± 0.02	3.69b ± 0.02	3.20c.e ± 0.01	3.39bc ± 0.02	3.39bc ± 0.07	3.35bc ± 0.06	3.62b ± 0.07
Urea (22.5 kg ha^{-1}) + Press mud (2500 kg ha^{-1})	3.27ef ± 0.09	3.55bc ± 0.02	3.46cd ± 0.02	3.59bc ± 0.04	3.86a ± 0.02	3.52b ± 0.09	3.21cd ± 0.05	3.41bc ± 0.10	3.53b ± 0.04	4.09a ± 0.08
Urea (33.75 kg ha^{-1}) + Press mud (1000 kg ha^{-1})	1.92lm ± 0.03	1.95k.m ± 0.01	1.86m ± 0.01	2.04j.l ± 0.01	1.91lm ± 0.31	2.61g.i ± 0.07	2.54h.j ± 0.01	2.28j.l ± 0.02	2.69f.h ± 0.01	2.90e.g ± 0.05
	2.82B					2.95A				
	LSD@0.05 {Year-2022 ± 0.1350, Year-2023 ± 0.3007, Year Interaction ± 0.0466}									
Grain's yield (t ha^{-1})										
Urea (45 kg ha^{-1})	3.22jk ± 0.18	3.05k ± 0.11	3.31jk ± 0.33	3.33j ± 0.03	3.82i ± 0.01	4.42gh ± 0.22	3.93j.l ± 0.24	4.64fg ± 0.15	4.64fg ± 0.41	4.80f ± 0.12
Press mud (10000 kg ha^{-1})	3.80i ± 0.38	3.93hi ± 0.24	4.39fg ± 0.03	4.42fg ± 0.12	4.58ef ± 0.02	5.28d ± 0.02	4.15ij ± 0.01	5.29d ± 0.02	5.28d ± 0.61	5.04e ± 0.05
Urea (11.25 kg ha^{-1}) + Press mud (5000 kg ha^{-1})	4.19gh ± 0.43	3.73i ± 0.19	4.79de ± 0.01	4.93cd ± 0.59	5.14bc ± 0.06	3.64m ± 0.12	3.25n ± 0.31	3.76lm ± 0.07	3.57m ± 0.81	3.64m ± 0.04
Urea (22.5 kg ha^{-1}) + Press mud (2500 kg ha^{-1})	4.67d.f ± 0.05	4.65ef ± 0.07	5.23b ± 0.03	5.21b ± 0.63	5.86a ± 0.03	5.66bc ± 0.31	5.46cd ± 0.10	5.69b ± 0.09	5.66bc ± 0.08	5.95a ± 0.05
Urea (33.75 kg ha^{-1}) + Press mud (1000 kg ha^{-1})	3.22jk ± 0.02	3.14jk ± 0.44	3.38j ± 0.09	3.82i ± 0.72	4.46fg ± 0.07	3.89kl ± 0.38	3.59m ± 0.15	4.21hi ± 0.19	4.08i.k ± 0.11	4.46g ± 0.03
	4.17B					4.56A				
	LSD@0.05 {Year-2022 ± 0.2765, Year-2023 ± 0.2273, Year Interaction ± 0.0507}									
Fodder yield (t ha^{-1})										
Urea (45 kg ha^{-1})	8.99gh ± 0.33	9.18fg ± 0.05	9.16f.h ± 0.08	9.11f.h ± 0.04	10.31b ± 0.04	9.87e ± 0.02	9.90e ± 0.15	10.0e ± 0.09	9.48e ± 0.28	11.11b.d ± 0.88
Press mud (10000 kg ha^{-1})	10.09bc ± 0.10	8.86h ± 0.44	9.40ef ± 0.01	9.69de ± 0.03	9.99cd ± 0.03	11.06b.d ± 0.01	11.06b.d ± 0.01	11.38bc ± 0.08	10.91cd ± 0.31	11.35bc ± 0.77
Urea (11.25 kg ha^{-1}) + Press mud (5000 kg ha^{-1})	6.35kl ± 0.08	4.79o ± 0.34	6.38k ± 0.11	5.21n ± 0.02	7.47j ± 0.52	8.34fg ± 0.15	8.16g ± 0.17	8.43fg ± 0.07	8.17g ± 0.51	8.74f ± 0.67
Urea (22.5 kg ha^{-1}) + Press mud (2500 kg ha^{-1})	9.58e ± 0.02	7.34j ± 0.54	9.61e ± 0.12	8.24i ± 0.21	11.03a ± 0.25	9.83e ± 0.31	10.62d ± 0.10	11.58b ± 0.05	11.60b ± 0.22	12.62a ± 0.09
Urea (33.75 kg ha^{-1}) + Press	5.81m ± 0.07	4.27p ± 0.05	5.43n ± 0.10	4.03p ± 0.04	6.06lm ± 0.04	9.45e ± 0.01	9.54e ± 0.02	9.61e ± 0.12	9.80e ± 0.01	9.79e ± 0.07
Different letters represent the level of significant among treatment means at probability level @ 5%										

	2022					2023				
Soil organic nitrogen application / Moringa application	**Control**	**Hydro primed**	**Moringa Bio-priming**	**Moringa spray**	**Bio-priming + Moringa spray**	**Control**	**Hydro primed**	**Moringa Bio-priming**	**Moringa spray**	**Bio-priming + Moringa spray**
mud (1000 kg ha^{-1})										
	7.85B					10.09A				
	LSD@0.05 {Year-2022 ± 0.3114, Year-2023 ± 0.5729, Year Interaction ± 0.0968}									
Total biological yield (t ha^{-1})										
Urea (45 kg ha^{-1})	11.09f ± 0.03	11.25f ± 0.05	11.21f ± 0.05	11.26f ± 0.08	12.56cd ± 0.02	11.93ij ± 0.02	11.97ij ± 0.15	12.18h.j ± 0.10	11.85ij ± 0.13	13.68f ± 0.13
Press mud (10000 kg ha^{-1})	13.02b ± 0.12	12.23d ± 0.10	12.45d ± 0.07	12.99b ± 0.05	13.18b ± 0.03	14.04d.f ± 0.01	13.77ef ± 0.02	14.42c.e ± 0.17	13.90d.f ± 0.08	14.55b.d ± 0.03
Urea (11.25 kg ha^{-1}) + Press mud (5000 kg ha^{-1})	9.52g ± 0.15	8.01i ± 0.09	9.59g ± 0.05	8.68h ± 0.03	11.17f ± 0.03	11.54j ± 0.15	11.54j ± 0.15	11.82ij ± 0.13	11.53j ± 0.07	12.37hi ± 0.14
Urea (22.5 kg ha^{-1}) + Press mud (2500 kg ha^{-1})	12.85bc ± 0.04	10.90f ± 0.02	13.08b ± 0.03	11.84e ± 0.14	14.88a ± 0.04	13.35fg ± 0.30	13.83ef ± 0.01	14.99bc ± 0.09	15.14b ± 0.04	16.71a ± 0.15
Urea (33.75 kg ha^{-1}) + Press mud (1000 kg ha^{-1})	7.743i ± 0.14	6.22k ± 0.06	7.29j ± 0.05	6.07k ± 0.12	7.97i ± 0.33	12.06h.j ± 0.03	12.08h.j ± 0.09	11.90ij ± 0.07	12.49hi ± 0.01	12.69gh ± 0.06
	10.68B					13.05A				
	LSD@0.05 {Year-2022 ± 0.3602, Year-2023 ± 0.7002, Year Interaction ± 0.1118}									
Harvest index (%)										
Urea (45 kg ha^{-1})	29.05kl ± 0.78	27.15l ± 0.19	29.55j.l ± 0.20	29.61j.l ± 0.13	30.44jk ± 0.19	37.05b.f ± 0.20	32.80g.k ± 0.52	38.16bc ± 0.28	39.45b ± 0.42	35.11e.i ± 0.49
Press mud (10000 kg ha^{-1})	29.18kl ± 0.74	32.19ij ± 0.48	35.32h ± 0.33	34.04hi ± 0.36	34.74hi ± 0.22	37.67b.e ± 0.14	30.11k.n ± 0.11	36.71b.f ± 0.44	38.00b.d ± 0.24	34.62f.j ± 0.39
Urea (11.25 kg ha^{-1}) + Press mud (5000 kg ha^{-1})	44.07de ± 0.19	46.65d ± 0.85	49.92c ± 0.35	56.81b ± 0.58	46.02d ± 0.87	31.64k.m ± 0.41	28.24n ± 0.29	31.84j.m ± 0.42	31.04k.n ± 0.27	29.42mn ± 0.68
Urea (22.5 kg ha^{-1}) + Press mud (2500 kg ha^{-1})	36.36h ± 0.50	42.74ef ± 0.62	39.99fg ± 0.34	44.13e ± 0.65	39.37g ± 0.17	42.46a ± 1.16	39.51b ± 0.05	37.99b.e ± 0.17	37.39b.f ± 0.12	35.64c.g ± 0.77
Urea (33.75 kg ha^{-1}) + Press mud (1000 kg ha^{-1})	41.60e.g ± 0.11	50.44c ± 0.36	46.39d ± 0.16	62.86a ± 0.28	55.91b ± 0.75	32.32i.l ± 0.15	29.69l.n ± 1.04	35.45c.h ± 0.18	32.75h.k ± 0.05	35.17d.i ± 0.39
	40.58A					34.81B				
	LSD@0.05 {Year-2022 ± 2.7550, Year-2023 ± 2.8803, Year Interaction ± 0.5617}									
Different letters represent the level of significant among treatment means at probability level @ 5%										

Proso-millet physiological attributes

The exogenous application of moringa significantly affected the physiological attributes including's chlorophyll contents, water use efficiency (WUE) and nitrogen use efficiency (NUE) under various doses of soil organic nitrogen during the both years of trails (Table 4). Biopriming + moringa spray enhanced the chlorophyl contents (*a*, *b*) under the applied soil dose of urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) in second year than first year of the trials (Table 4).

The treated plants with bio-priming + moringa spray increased the water use efficiency with the additional application of urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) as compared to hydro primed, moringa

Table 4
Evaluation of moringa priming with press mud application on the physiological behavior of proso-millet crop

	2022					2023				
Soil organic nitrogen application / Moringa application	**Control**	**Hydro primed**	**Moringa Bio-priming**	**Moringa spray**	**Bio-priming + Moringa spray**	**Control**	**Hydro primed**	**Moringa Bio-priming**	**Moringa spray**	**Bio-priming + Moringa spray**
Chlorophyll a (mg g^{-1})										
Urea (45 kg ha^{-1})	0.69ij ± 0.02	0.70h.j ± 0.02	1.35bc ± 0.04	1.36bc ± 0.05	1.50b ± 0.06	1.67hi ± 0.01	1.86fg ± 0.11	1.84g ± 0.13	1.84g ± 0.06	1.96ef ± 0.12
Press mud (10000 kg ha^{-1})	1.09d.f ± 0.01	0.86f.i ± 0.05	1.22c.e ± 0.03	1.03d.g ± 0.06	1.48b ± 0.02	1.60h.j ± 0.02	1.95ef ± 0.01	2.00de ± 0.08	2.18bc ± 0.04	2.25b ± 0.21
Urea (11.25 kg ha^{-1}) + Press mud (5000 kg ha^{-1})	0.37k ± 0.01	0.83f.i ± 0.07	0.55jk ± 0.06	0.99e.g ± 0.03	1.18c.e ± 0.02	1.36mn ± 0.09	1.44k.m ± 0.15	1.47kl ± 0.07	1.44k.m ± 0.06	1.53jk ± 0.23
Urea (22.5 kg ha^{-1}) + Press mud (2500 kg ha^{-1})	0.96e.h ± 0.02	0.68ij ± 0.03	1.43bc ± 0.04	1.37bc ± 0.08	2.45a ± 0.05	1.59ij ± 0.03	1.71h ± 0.12	2.02de ± 0.05	2.10cd ± 0.12	2.85a ± 0.02
Urea (33.75 kg ha^{-1}) + Press mud (1000 kg ha^{-1})	0.53jk ± 0.04	0.82g.i ± 0.01	1.22c.e ± 0.02	0.72h.j ± 0.01	1.26b.d ± 0.07	1.22o ± 0.05	1.22o ± 0.05	1.38lm ± 0.01	1.26no ± 0.01	1.47kl ± 0.04
	1.06B					1.73A				
	LSD@0.05 {Year-2022 ± 0.2612, Year-2023 ± 0.1035, Year Interaction ± 0.0390}									
Chlorophyll b (mg g^{-1})										
Urea (45 kg ha^{-1})	0.27hi ± 0.01	0.44d ± 0.05	0.40e ± 0.01	0.33f ± 0.01	0.46c ± 0.01	0.43i.l ± 0.04	0.56e.j ± 0.02	0.52f.k ± 0.06	0.58e.j ± 0.01	0.52f.k ± 0.10
Press mud (10000 kg ha^{-1})	0.21m ± 0.02	0.51b ± 0.01	0.34f ± 0.03	0.33f ± 0.03	0.51b ± 0.03	0.33l ± 0.01	0.62e.h ± 0.10	0.73c.e ± 0.02	0.95b ± 0.03	0.88bc ± 0.12
Urea (11.25 kg ha^{-1}) + Press mud (5000 kg ha^{-1})	0.18n ± 0.01	0.25j.l ± 0.03	0.24kl ± 0.01	0.24l ± 0.02	0.25i.k ± 0.03	0.34l ± 0.01	0.42i.l ± 0.01	0.41j.l ± 0.05	0.37kl ± 0.02	0.47g.l ± 0.10
Urea (22.5 kg ha^{-1}) + Press mud (2500 kg ha^{-1})	0.29g ± 0.04	0.40e ± 0.01	0.40e ± 0.04	0.43d ± 0.01	0.66a ± 0.02	0.59e.i ± 0.20	0.67d.f ± 0.02	0.93b ± 0.06	0.80b.d ± 0.07	1.32a ± 0.08
Urea (33.75 kg ha^{-1}) + Press mud (1000 kg ha^{-1})	0.19n ± 0.01	0.26h.j ± 0.02	0.25i.k ± 0.01	0.22m ± 0.05	0.27h ± 0.01	0.45h.l ± 0.19	0.72c.e ± 0.03	0.52f.k ± 0.09	0.59e.i ± 0.08	0.65d.g ± 0.05
	0.33B					0.61A				
	LSD@0.05 {Year-2022 ± 0.0150, Year-2023 ± 0.1796, Year Interaction ± 0.0252}									
Water use efficiency										
Urea (45 kg ha^{-1})	1.51i ± 0.01	1.77f.h ± 0.02	1.73gh ± 0.04	1.99c.e ± 0.01	2.05b.d ± 0.03	1.85g ± 0.11	2.06c ± 0.01	1.97d ± 0.01	1.89f ± 0.03	2.11b ± 0.01
Press mud (10000 kg ha^{-1})	1.55i ± 0.19	1.75f.h ± 0.02	1.66hi ± 0.04	1.86e.g ± 0.09	2.16b ± 0.02	1.55i ± 0.01	1.95e ± 0.03	1.44k ± 0.07	1.65h ± 0.05	2.10b ± 0.03
Urea (11.25 kg ha^{-1}) + Press mud (5000 kg ha^{-1})	0.81n ± 0.17	0.82mn ± 0.01	0.80n ± 0.01	0.90l.n ± 0.01	0.99kl ± 0.01	1.07q ± 0.13	1.15o ± 0.05	1.15no ± 0.09	1.04r ± 0.01	1.35l ± 0.04
Urea (22.5 kg ha^{-1}) + Press mud	1.17j ± 0.20	1.92d.f ± 0.01	2.22b ± 0.01	2.11bc ± 0.02	2.48a ± 0.02	1.56i ± 0.015	1.96e ± 0.01	1.46j ± 0.10	1.66h ± 0.01	2.18a ± 0.01
Different letters represent the level of significant among treatment means at probability level @ 5%										

	2022					2023				
Soil organic nitrogen application / Moringa application	**Control**	**Hydro primed**	**Moringa Bio-priming**	**Moringa spray**	**Bio-priming + Moringa spray**	**Control**	**Hydro primed**	**Moringa Bio-priming**	**Moringa spray**	**Bio-priming + Moringa spray**
(2500 kg ha^{-1})										
Urea (33.75 kg ha^{-1}) + Press mud (1000 kg ha^{-1})	0.97k.n ± 0.23	1.05j.l ± 0.01	0.99k.m ± 0.01	0.88ln ± 0.01	1.13jk ± 0.01	0.95t ± 0.019	1.11p ± 0.06	1.00s ± 0.14	1.16n ± 0.04	1.19m ± 0.06
	1.49B					1.54A				
	LSD@0.05 {Year-2022 ± 0.1692, Year-2023 ± 0.0124, Year Interaction ± 0.0234}									
Nitrogen use efficiency										
Urea (45 kg ha^{-1})	875.2o ± 0.57	885.8n ± 0.56	864.8p ± 0.09	874.8o ± 0.29	894.4m ± 0.81	989.7h ± 1.13	991.2h ± 0.56	982.6i ± 0.38	989.9h ± 0.32	1014.6g ± 0.78
Press mud (10000 kg ha^{-1})	1264.8h ± 1.54	1278.7f ± 0.17	1261.1h ± 0.19	1273.4g ± 0.80	1316.2e ± 0.41	1328.6f ± 1.11	1331.2e ± 0.17	1324.9f ± 0.26	1337.2d ± 0.61	1336.3d ± 0.21
Urea (11.25 kg ha^{-1}) + Press mud (5000 kg ha^{-1})	722.4qr ± 0.88	726.4q ± 0.51	721.0r ± 0.71	724.6qr ± 1.06	721.0r ± 1.23	773.6n ± 0.89	770.0no ± 0.51	768.6o ± 0.74	773.7n ± 0.81	806.2m ± 0.29
Urea (22.5 kg ha^{-1}) + Press mud (2500 kg ha^{-1})	1666.0c ± 1.38	1673.8b ± 0.93	1652.4d ± 0.14	1669.2c ± 0.08	1719.6a ± 0.90	1773.5b ± 0.29	1765.5c ± 0.93	1765.0c ± 0.29	1773.4b ± 0.43	1819.6a ± 0.66
Urea (33.75 kg ha^{-1}) + Press mud (1000 kg ha^{-1})	1107.2k ± 0.96	1113.9j ± 0.37	1101.8l ± 0.80	1103.2kl ± 0.73	1201.4i ± 0.66	840.8kl ± 0.53	844.0k ± 0.41	837.1l ± 0.37	837.8l ± 1.39	859.2j ± 0.74
	1136.5B					1145.4A				
	LSD@0.05 {Year-2022 ± 4.6193, Year-2023 ± 3.9782, Year Interaction ± 0.8523}									
Different letters represent the level of significant among treatment means at probability level @ 5%										

Bio-priming, moringa spray during the both years of experimental exploration (Table 4). According to 2nd year of project study, the highest values of nitrogen use efficiency was observed in the plants after applied treatment of bio-priming + moringa spray than others treatments under soil organic nitrogen via urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) and lowest NUE by the use of single factor urea (45 kg ha^{-1}) followed by press mud (10000 kg ha^{-1}) in the both years (2022, 2023) of the trials (Table 4).

Proso-millet anti-oxidant behavior

The interactive effect of anti-oxidant contents after the application of moringa treatment along with soil organic nitrogen application in proso-millet plants was observed significant during the both years of project studies (Fig. 2). Results illustrated that plants treated with biopriming + moringa spray produced maximum enzymatic anti-oxidant contents including's total soluble proteins (TSP), superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) under the applied soil dose of urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) followed by urea (11.25 kg ha^{-1}) + Press mud (5000 kg ha^{-1}) as compared to Urea (45 kg ha^{-1}) during the year-II than year-I shown in the Fig. 2. Similarly, results demonstrated that combine use of biopriming + moringa spray triggered the non-enzymatic contents to release the greater values of ascorbic acid (AsA), and total phenolic contents (TPC) in the plants treatment with soil application of urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) during the both years of the experimental trials (Fig. 2). Year's interaction was observed significant with anti-oxidant values in the plants of proso-millet crop and higher contents was detected during 2nd year than 1st year of the trials (Fig. 2).

Economic analysis

Table 5 illustrated the economic analysis for cultivation of proso-millet crop under applied treatment of co-application of moringa plus soil organic nitrogen dose during the average both years of 2022 and 2023. Data revealed that combine use of bio-priming with moringa spray achieved highest out-put in net income & benefit cost ratio under the use of soil amendments with urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) as compared to other treatments shown in the Table 5.

Table 5
Economic analysis of applied moringa with press mud application for proso-millet production during average both years 2022 and 2023

Soil organic nitrogen application	Moringa application	Total expenditure (US$ ha^{-1})	Gross income (US$ ha^{-1})	Net income (US$ ha^{-1})	Benefit cost ratio (BCR)
Urea (45 kg ha^{-1})	Control	182.41	367.65	185.24	1.02
	Hydro primed	176.86	379.04	202.18	1.14
	Moringa Bio-priming	180.09	354.89	174.80	0.97
	Moringa spray	176.18	345.18	169.00	0.96
	Bio-priming + Moringa spray	176.08	381.00	204.92	1.16
Press mud (10000 kg ha^{-1})	Control	149.92	314.81	164.88	1.10
	Hydro primed	156.42	319.11	162.69	1.04
	Moringa Bio-priming	153.20	301.72	148.52	0.97
	Moringa spray	167.68	336.75	169.07	1.01
	Bio-priming + Moringa spray	179.56	385.63	206.07	1.15
Urea (11.25 kg ha^{-1}) + Press mud (5000 kg ha^{-1})	Control	152.55	261.52	108.97	0.71
	Hydro primed	144.13	269.85	125.73	0.87
	Moringa Bio-priming	163.61	307.41	143.80	0.88
	Moringa spray	161.08	305.92	144.84	0.90
	Bio-priming + Moringa spray	157.26	304.91	147.65	0.94
Urea (22.5 kg ha^{-1}) + Press mud (2500 kg ha^{-1})	Control	169.49	369.75	200.26	1.18
	Hydro primed	161.85	347.26	185.41	1.15
	Moringa Bio-priming	162.04	356.85	194.80	1.20
	Moringa spray	165.08	354.30	189.23	1.15
	Bio-priming + Moringa spray	162.11	420.25	258.14	1.59
Urea (33.75 kg ha^{-1}) + Press mud (1000 kg ha^{-1})	Control	151.03	319.48	168.45	1.12
	Hydro primed	145.72	295.28	149.56	1.03
	Moringa Bio-priming	148.62	275.28	126.66	0.85
	Moringa spray	143.45	273.02	129.57	0.90
	Bio-priming + Moringa spray	151.15	313.30	162.16	1.07

Pearson correlation analysis

Pearson correlation interactive effect was found significant among the attributes observed after the use of treatments moringa application via seed priming + foliar spray in the proso-millet crop under the induced soil organic nitrogen doses during the average both years year-I & II of project studies presented in the Table 6.

Table 6

Pearson correlation analysis after applied treatments of moringa with press mud application for proso-mi

	Aerial biomass yield	Ascorbic acid	Catalase	Chl. *a*	Chl. *b*	Fodder yield	1000-Grain's weight	Grains' Yield	Harvest index	Length panicle	Number leaves plant^{-1}	Number grains' panicle^{-1}	Num tillers plant
Ascorbic acid	0.6945												
P-Value	0.0000												
Catalase	0.3202	0.1844											
	0.0051	0.1132											
Chl. a	0.2901	0.3103	-0.2862										
	0.0116	0.0067	0.0128										
Chl. b	0.3423	0.4292	0.1706	0.7103									
	0.0026	0.0001	0.1433	0.0000									
Fodder yield	0.1427	0.2992	-0.1612	0.7772	0.6656								
	0.2221	0.0091	0.1670	0.0000	0.0000								
1000-Grain's weight	0.1581	0.2522	-0.0742	0.7552	0.7426	0.7377							
	0.1754	0.0291	0.5267	0.0000	0.0000	0.0000							
Grains' Yield	0.2918	0.3743	-0.0772	0.6973	0.6216	0.8094	0.6796						
	0.0111	0.0009	0.5105	0.0000	0.0000	0.0000	0.0000						
Harvest index	-0.0786	0.0463	-0.1325	0.3523	0.2961	0.3931	0.4096	0.8012					
	0.5028	0.6933	0.2570	0. 0019	0.0099	0.0005	0.0003	0.0000					
Length panicle	0.3421	0.2325	-0.0598	0.8104	0.6025	0.6355	0.7451	0.7526	0.5335				
	0.0027	0.0448	0.6101	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000				
Number leaves plant^{-1}	0.1912	0.2200	-0.1921	0.8857	0.6484	0.7474	0.8022	0.6602	0.3618	0.7965			
	0.1004	0.0579	0.0987	0.0000	0.0000	0.0000	0.0000	0.0000	0.0014	0.0000			
Number grains' panicle^{-1}	0.1708	0.0991	-0.2002	0.0074	-0.134	-0.2820	-0.0772	-0.3185	-0.3309	-0.0830	0.0183		
	0.1428	0.3978	0.0850	0.9500	0.2513	0.0142	0.5104	0.0054	0.0037	0.4789	0.8764		
Number tillers plant^{-1}	-0.0749	-0.1615	0.5813	0.1054	0.2963	0.2815	0.3139	0.2613	0.2230	0.1958	0.1731	-0.2982	
	0.5228	0.1662	0.0000	0.3683	0.0099	0.0144	0.0061	0.0236	0.0545	0.0922	0.1376	0.0094	
Nitrogen use efficiency	0.4410	0.5270	-0.0161	0.6783	0.6216	0.7681	0.6381	0.8984	0.6044	0.7585	0.5783	-0.3272	0.144
	0.0001	0.0000	0.8908	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0042	0.216
Peroxidase	0.0649	0.1548	0.3136	0.4771	0.6105	0.7169	0.6405	0.7618	0.5929	0.6304	0.5090	-0.5591	0.613
	0.5800	0.1848	0.0062	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000
Panicle weight	0.7342	0.6081	0.1507	0.6929	0.6719	0.5946	0.6021	0.6499	0.2345	0.6789	0.6388	0.0610	0.139
	0.0000	0.0000	0.1970	0.0000	0.0000	0.0000	0.0000	0.0000	0.0428	0.0000	0.0000	0.6031	0.232
Plant height	0.2671	0.2810	-0.2386	0.9046	0.6810	0.7832	0.8130	0.7748	0.4843	0.8773	0.8870	0.0459	0.167
	0.0205	0.0146	0.0392	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.6957	0.150
Superoxide dismutase	0.6841	0.3857	0.5188	0.3280	0.4027	0.1473	0.3134	0.3299	0.1136	0.6062	0.3465	0.1686	0.261
	0.0000	0.0006	0.0000	0.0041	0.0003	0.2073	0.0062	0.0038	0.3319	0.0000	0.0023	0.1483	0.023
Total biological yield	0.5147	0.5303	-0.0145	0.7872	0.7108	0.9220	0.7012	0.8155	0.3102	0.6850	0.7228	-0.1774	0.214
	0.0000	0.0000	0.9015	0.0000	0.0000	0.0000	0.0000	0.0000	0.0068	0.0000	0.0000	0.1278	0.064
Total phenolic contents	0.4840	0.2667	0.6636	0.1393	0.3490	0.1582	0.2282	0.2993	0.1484	0.4596	0.2215	0.0339	0.416
	0.0000	0.0207	0.0000	0.2332	0.0021	0.1752	0.0489	0.0091	0.2039	0.0000	0.0561	0.7728	0.000

	Aerial biomass yield	Ascorbic acid	Catalase	Chl. *a*	Chl. *b*	Fodder yield	1000-Grain's weight	Grains' Yield	Harvest index	Length panicle	Number leaves plant^{-1}	Number grains' panicle^{-1}	Num tillers plant
Total soluble protein	0.3747	0.1944	0.7089	0.0836	0.3220	-0.0218	0.2163	0.1092	0.0294	0.3964	0.1878	-0.0128	0.419
	0.0009	0.0947	0.0000	0.4760	0.0048	0.8530	0.0623	0.3512	0.8020	0.0004	0.1066	0.9130	0.000
Water use efficiency	-0.0959	-0.0461	-0.4611	0.7744	0.4056	0.6315	0.7046	0.5487	0.4056	0.7585	0.7256	-0.0258	0.111
	0.4130	0.6946	0.0000	0.0000	0.0003	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000	0.8262	0.339

Discussion

Currently, there is no published literature on the combine use of moringa and soil organic fertilization on the morphological growth attributes of proso-millet crop in the regions with an agricultural arid zone environment. Interestingly, plant height, number of leaves plant^{-1}, number of tillers plant^{-1}, length of panicle, and panicle weight of proso-millet crop after application of biopriming + moringa spray along with soil urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) treatments might be the reason to stimulate the potential increase of water absorption capacity, higher mobilization of reserve food, and rapid seedlings establishment [29]. This can be the possible due to the greater photosynthetic rate, better net assimilation rate, and more accumulation of dry matter production during the proso-millet crop cultivation by the use of biopriming + moringa spray along with soil conditioning of urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) [22]. The promotion in the proso-millet plants in terms of morphological growth by the application of biopriming + moringa spray and soil urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) could result in enhancing the cell wall plasticity subsequently trigger the hydrolysis process by converting the starch into sugar molecules as well as reducing the water potential for cell elongation [3].

The treatment applied biopriming + moringa spray activated the tolerance mechanism by upgrading the enzymatic and non-enzymatic anti-oxidants values in the proso-millet plants under the induced soil urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) dose might be the reason to achieve the significant tolerance for performing the better growth and development activities [12]. The treated plants with biopriming + moringa spray may be triggered the highest production of anti-oxidants for scavenges of ROS activities and balanced the ionic homeostasis level under the use of soil conditioner soil urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) during the experimental trials (Year-I & II) [13]. Observations proved that moringa application potentially upgraded of anti-oxidants behavior might be the reason by tolerance in the proso-millet plants against cellular oxidative damaging level and providing the effective chances of survival under the addition of soil organic nitrogen application of soil urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) [15]. Biopriming + moringa spray motivated the generation of enzymatic and non-enzymatic anti-oxidants in the plants under treated soil urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) could be possible to accommodate the favorable environment during the various processes of respiration, evaporation, and photosynthesis [18]. It is evidence that proso-millet plants detoxified the ROS molecules (H_2O_2, O_2H, $^1O_2$) after applied treatment of biopriming + moringa spray under soil urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) dose might be the reason due to the overproduction of anti-oxidants act as a protective reagent of anti-oxidant defense system during the various physiological functions [14].

The increasing trend in physiological attributes in the proso-millet plants after the application of treatments biopriming + moringa spray might be due to higher chlorophyll contents (Chl *a* & *b*) which favor in performing the better photosynthetic rate and more photosynthetic efficiency under the applied soil treatment having urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) during the trials (2022 and 2023) [7]. Activation of proso-millet plant defense system allowed to obtain the maximum chlorophyll contents (Chl *a* & *b*) by the treatment application of biopriming + moringa spray along-with the soil organic nitrogen dose of urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) could be the possible reason of greater accumulation of dry matter and photo-assimilates during the photosynthesis process [34]. Observations described that biopriming + moringa spray favored the proso-millet plants in better utilization of moisture during the early and synchronized tillers establishment could be possible due to the proficient availability of natural resources during the phenological crop growth stages under the applied soil avengement's dose urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) [35].

The application of fertilizers, especially nitrogen is the most important aspect. It is directly proportional to the proso-millet grains yield. In this project study, the applied nitrogen application via using the urea and press mud in the experimental soil could improve the productivity of proso-millet crop [9]. Results also illustrated that treatment having additional use of nitrogen application did not enhance the grains productivity of proso-millet crop. Greater nitrogen use efficiency in the proso-millet plants achieved higher grains yield by the treatment applied in the experimental soil having urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) dose might be the reason of accurate and optimize way of applied nitrogen application method [36]. Biopriming + moringa spray boosted up nitrogen use efficiency might be the reason to facilitate the proso-millet plants for better nitrogen absorption under this format of applied soil organic nitrogen dose of urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) [17].

Proso-millet grains production is the result of combine effect of various yield related attributes such as the number of grains panicle^{-1}, 1000 grains weight, and aerial biomass yield, obtained under specific growing conditions [37]. The applied treatment of biopriming + moringa spray enhanced the grain's yield, fodder yield, total biological yield, harvest index under soil nitrogen dose of urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) might be due to the reason for notable increasing trend in grains count and weight during the experimental trial (2022, 2023) [19]. Observations proved that moringa application boosted up the grains development periods related to graining filling rate by performing better photosynthesis, vigorous leaves formations and favorable source-sink relationships may be the reason for achieving higher grains production during the addition of soil conditioning via urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) treatment [38]. In this project study, fodder yield is directly proportional to the better availability of nutrients especially nitrogen. The applied treatment soil nitrogen dose of urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) might be the reason to promote the uptake of essential nutrients and moisture absorbance for producing significantly higher vegetative growth in term of fodder yield in the both years of trials [39]. Harvest index is the most important yield characteristic that indicates the percentage transfer of photosynthetic products from plants to its grains. The combine use of moringa application (biopriming + moringa spray) under soil nitrogen dose (urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) obtained the lesser harvest index might be the reason due to greater tillers production affected in dry matter straw production than in the grains yield [40]. The performance of all parameters in proso-millet crop after treatment applied moringa along-with soil nitrogen dose was observed due to its rapid germination potential, utilization of reserved food, production of synchronized tillers, better performance in physiological processes, defensive behavior in anti-oxidants and ROS activities [2].

Benefit cost ratio (BCR) described the financial metric to check the economic efficiency during the cultivation of proso-millet crop in this project study. The measured economic analysis emphasized the higher results in term of maximum net income and BCR in the treatment applied biopriming + moringa spray economic might be the reason due to cost-effective and easily adoptable approach helpful for enhancing the proso-millet grains production under the soil nitrogen dose of (urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) as per others [41, 16].

Conclusion

Notable increasing trend in the grains and fodders production of proso-millet crop after the treatment applied bio-priming plus moringa spray under the use of soil organic nitrogen via urea (22.5 kg ha^{-1}) + press mud (2500 kg ha^{-1}) by potential anti-oxidants defense behavior, better efficiency in WUE, and NUE can be recommended for cultivation under the unfavorable arid and semi-arid environmental condition.

Declarations

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Data availability

All data generated or analyzed during this study are included in this published article.

Ethics approval and consent to participate

Not Applicable.

Consent for publication

Not Applicable.

Competing interests

The authors declare no competing interests.

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Figures

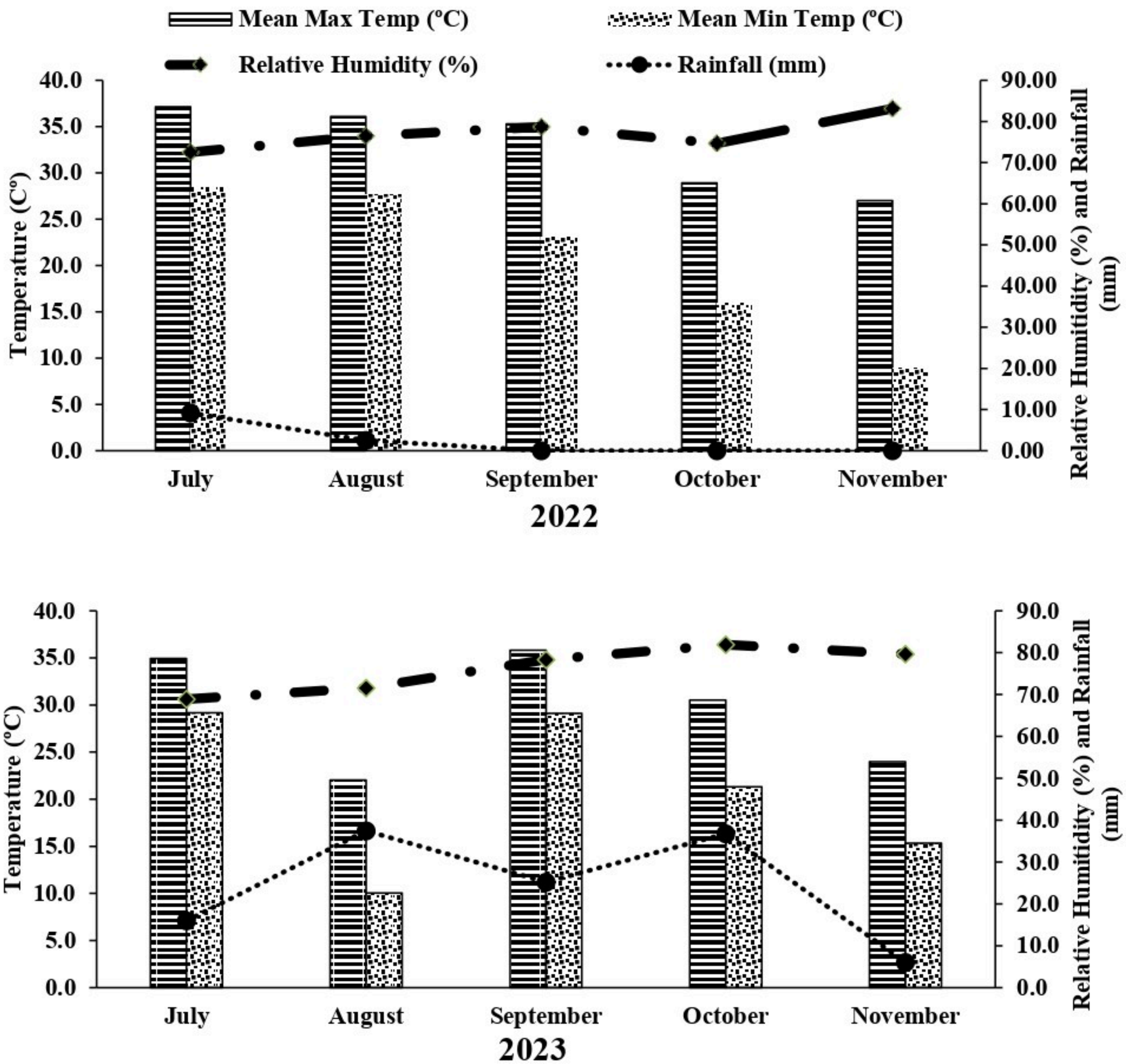

Figure 1

Meteorological data during the phenological growth stages of proso-millet crop production

Meteorological station at Central Cotton Research Institute Multan, Pakistan

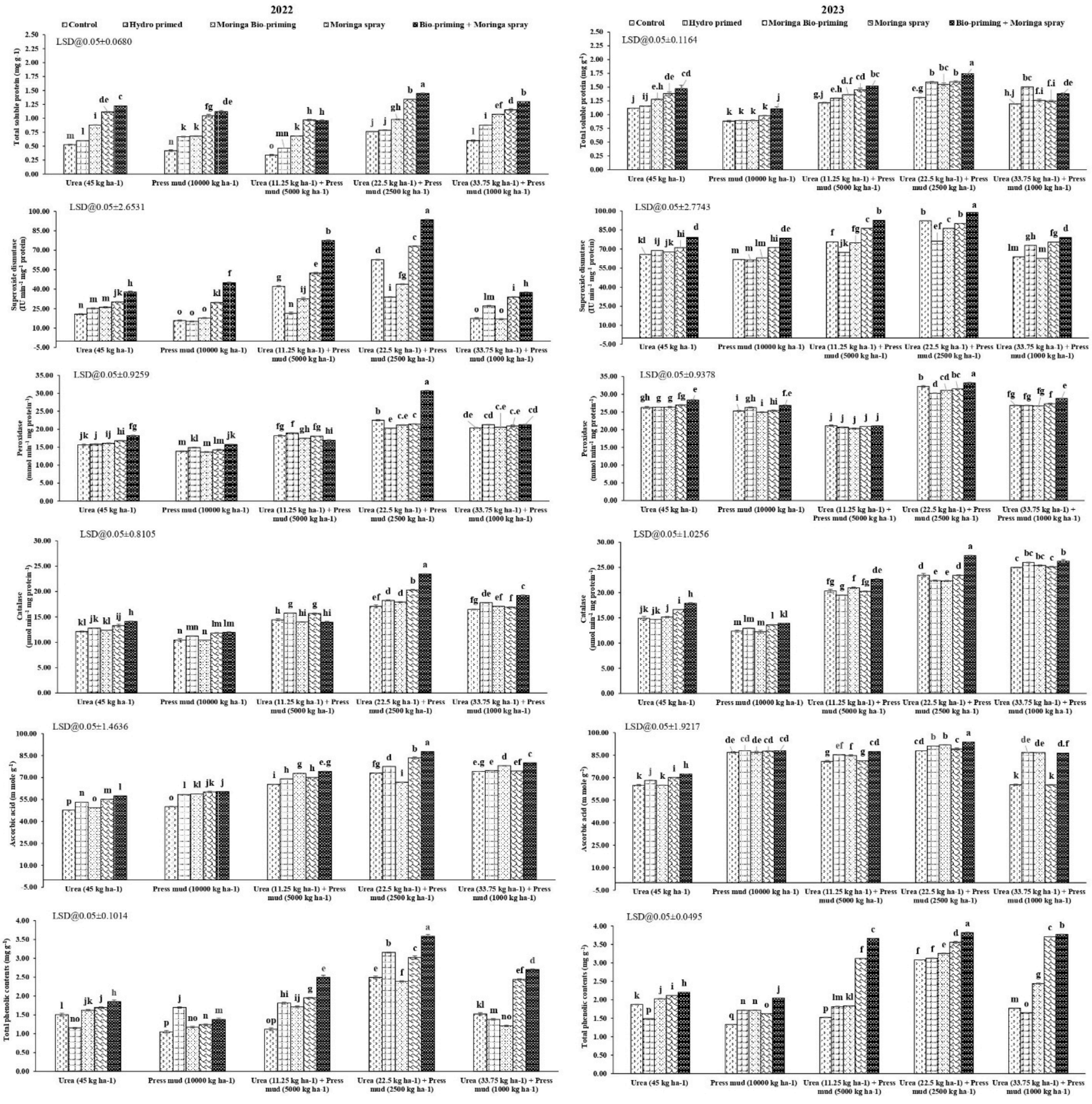

Figure 2

Evaluation of moringa priming with press mud application on the anti-oxidants behavior of proso-millet crop