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RESEARCH ARTICLE

Influence of seed hardening, soil and foliar nutrition of pearl millet under rainfed conditions

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Abstract

Pearl millet, often called the 'Poor Man's Food,' is vital for millions of low-income households. A field experiment was conducted at Manathal village, Salem district, Tamil Nadu, during June-August 2021. The study followed an RBD design with three replications. There were altogether thirteen treatments *viz*., T_1 - Control, T_2 - Seed treatment with 2 % KCl + soil application of vermicompost (VC) @ 5 t ha^{-1}, T_3 - Seed treatment with 3 % *Panchagavya* + soil application of VC @ 5 t ha^{-1}, T_4 - Seed treatment with 2 % KCl + soil application of humic acid (HA) @ 25 kg ha^{-1}, T_5 - Seed treatment with 3 % *Panchagavya* + soil application of HA @ 25 kg ha^{-1}, T_6 - Seed treatment with 2 % Kcl + soil application of seaweed extract (SE) @ 25 kg ha^{-1}, T_7 - Seed treatment with 3 % *Panchagavya* + soil application of SE @ 25 kg ha^{-1}, T_8 - T_2 + foliar application of 19:19:19 @ 25 days after sowing (DAS), T_9 - T_3 + foliar application of 19:19:19 @ 25 DAS, T_{10} - T_4 + foliar application of 19:19:19 @ 25 DAS, T_{11} - T_5 + foliar application of 19:19:19 @ 25 DAS, T_{12} - T_6 + foliar application of 19:19:19 @ 25 DAS, T_{13} - T_7 + foliar application of 19:19:19 @ 25 DAS. Seed treatment with 2 % KCl + soil application of VC @ 5 t ha^{-1} + foliar spray of 19:19:19 @ 25 DAS (T_8) showed superior performance of pearl millet under rainfed conditions.

Keywords: 19:19:19; KCl; stress; rainfed; seed hardening

Introduction

Pearl millet (*Pennisetum glaucum* L.), commonly known as bajra, is cultivated extensively in arid and semi-arid regions of Asia and Africa. It is also referred to as candle millet, bulrush millet and spiked millet. As a C4 plant, pearl millet exhibits high photosynthetic efficiency, rapid biomass accumulation and superior adaptability to harsh agro-climatic conditions, including poor soil fertility, high temperatures and low rainfall (1). Its ability to grow on marginal lands with minimal inputs makes it crucial for ensuring food and nutritional security for vulnerable populations, particularly in dryland areas.

In India, pearl millet is the fourth most important crop after rice, wheat and maize. It is considered a "poor man's food" due to its accessibility and nutritional richness, being a good source of protein, fiber and micronutrients such as iron and zinc. Recognizing its importance, the Government of India celebrated 2018 as the "National Year of Millets" and the United Nations declared 2023 as the "International Year of Millets" to promote its global cultivation and consumption (2). Despite these initiatives, yields remain stagnant, primarily due to rainfed cultivation, limited nutrient availability and poor seedling establishment. There is a growing emphasis on developing integrated agronomic strategies that enhance productivity while sustaining soil health under resource-constrained conditions.

Seed hardening is a pre-sowing physiological technique proven to enhance germination and drought tolerance in dryland crops. Hardening pearl millet seeds with 2 % potassium chloride (KCl) induces osmotic adjustment, improves membrane integrity and accelerates metabolic activity during germination (3). In parallel, *Panchagavya*, a traditional organic bio stimulant made from cow-based products, has gained attention for its role in promoting seed vigour, enhancing microbial activity and inducing systemic resistance. Seed treated with *Panchagavya* is reported to reduce seedling mortality and enhance plant immunity under biotic and abiotic stress (4).

Once seeds are established, soil fertility becomes a limiting factor in millet systems due to the inherently nutrient-poor nature of sandy loam soils. The use of vermicompost, an organic amendment derived from decomposed organic matter via earthworms, improves soil structure, microbial diversity and nutrient availability. Vermicompost is rich in macro and micronutrients and stimulates plant growth hormones such as auxins and cytokinins (5). It also enhances soil cation exchange capacity, moisture retention and enzymatic activity, which are vital for sustainable pearl millet production under rainfed conditions (6).

Humic acid, another organic compound derived from decomposed plant material, plays a pivotal role in enhancing nutrient uptake and root proliferation. It improves the soil's physical and chemical properties, particularly in coarse-textured soils and has been shown to increase nutrient-use efficiency by enhancing the availability and absorption of nitrogen, phosphorus and potassium (7). Moreover, humic substances improve stress tolerance by activating antioxidant systems in plants.

Seaweed extracts are rich in natural plant growth regulators like auxins, cytokinins, gibberellins and essential micronutrients. Seaweed-based bio stimulants improve chlorophyll content, enzyme activity and resistance to abiotic stresses. Incorporating seaweed extract into soil enhances microbial colonization and promotes balanced nutrient uptake, thereby improving overall plant health and resilience (8). When applied in conjunction with organic manures and humic substances, seaweed extract contributes significantly to root zone development and reproductive efficiency in pearl millet.

Beyond soil amendments, foliar application of balanced nutrients offers an efficient strategy to counter nutrient deficiencies during critical growth stages. Foliar application bypasses soil barriers and delivers nutrients directly to the plant tissues, allowing for rapid assimilation. The application of water-soluble 19:19:19 (NPK) at 25 DAS has been shown to boost photosynthetic rate, tiller development and spike initiation. Foliar nutrition is 15-20 times more effective than soil fertilization, especially in rainfed areas where nutrient leaching is a concern (9).

The main reason for the low production in pearl millet has been regarded as cultivation on marginal lands by poor farmers, with minimal support from farmers and government agencies. There is a significant potential to increase yields. Over -reliance on inorganic fertilizers has harmed soil health and caused nutrient deficiencies. Integrating chemical fertilizers with organic nutrients is essential for maintaining soil health, productivity and stable crop yields.

Given the challenges of climate variability and declining soil health, such integrated nutrient and bio-stimulant management strategies are imperative for enhancing the resilience and productivity of pearl millet. These sustainable interventions not only support higher yields but also contribute to long-term soil health and ecological balance.

Material and Methods

The field experiment was conducted in a farmer's field at Manathal village, Tharamangalam block of Salem district, Tamil Nadu, during June to August 2021 to study the "Influence of seed hardening, soil and foliar nutrition of pearl millet under rainfed conditions". The experimental field was geographically located at 11°46' N latitude and 77°57' E longitude with an altitude of 225 m above the mean sea level in the North-Western Agro-climatic zone of Tamil Nadu. The experimental plots were laid out in a randomized block design with thirteen treatments and three replications. The CO (cu) 9 variety was chosen for the study. The treatments included in the experiment were T_1- Control (No seed hardening and nutrient application), T_2 - Seed treatment with 2 % KCl + soil application of vermicompost @ 5 t ha^{-1}, T_3 - Seed treatment with 3 % *Panchagavya* + soil application of vermicompost @ 5 t ha^{-1}, T_4- Seed treatment with 2 % KCl + soil application of humic acid @ 25 kg ha^{-1}, T_5- Seed treatment with 3 % *Panchagavya* + soil application of humic acid @ 25 kg ha^{-1}, T_6 - Seed treatment with 2 % Kcl + soil application of seaweed extract @ 25 kg ha^{-1}, T_7- Seed treatment with 3 % *Panchagavya* + soil application of seaweed extract @ 25 kg ha^{-1}, T_8 - T_2 + foliar application of 19:19:19 @ 25 DAS, T_9 - T_3 + foliar application of 19:19:19 @ 25 DAS, T_{10} - T_4 + foliar application of 19:19:19 @ 25 DAS, T_{11} - T_5 + foliar application of 19:19:19 @ 25 DAS, T_{12} - T_6 + foliar application of 19:19:19 @ 25 DAS, T_{13} - T_7 + foliar application of 19:19:19 @ 25 DAS. The texture of the experimental field soil was sandy loam with a pH of 6.8 and EC of 0.1dSm^{-1}. The soil was low in available nitrogen (209.80 kg ha^{-1}), medium in available phosphorus (18.61 kg ha^{-1}) and high in available potassium (305.24 kg ha^{-1}).

Results

Germination percentage

The germination percentage data is presented in Fig. 1. The germination percentage was significantly influenced by the seed hardening, soil and foliar nutrition of pearl millet under rainfed conditions. Among the different treatments experimented, T_2+ foliar application of 19:19:19 @ 25 DAS (T_8) recorded a maximum germination percentage of 94.49. The minimum germination percentage of 85.14 was recorded in the T_1 control (No seed hardening and nutrient application).

Plant height and dry matter production at the harvest stage

The appraisal of data presented in Table 1 revealed that the plant height and dry matter production at the harvest stage were significantly influenced by the seed hardening, soil and foliar nutrition of pearl millet under rainfed conditions. T_2+ foliar application of 19:19:19 @ 25 DAS (T_8) recorded the highest plant height (194.5 cm) and dry matter production (6,235 kg ha^{-1}) at the harvest stage of pearl millet under rainfed conditions. This was followed by seed treatment with T_4+ foliar application of 19:19:19 @ 25 DAS (T_{10}) recorded the plant height (189.0 cm) and dry matter production (5,960 kg ha^{-1}) at the harvest stage. The minimum plant height of (129.5 cm) and dry matter production (3056 kg ha^{-1}) were recorded under T_1 (No seed hardening and nutrient application) at the harvest stage of the pearl millet.

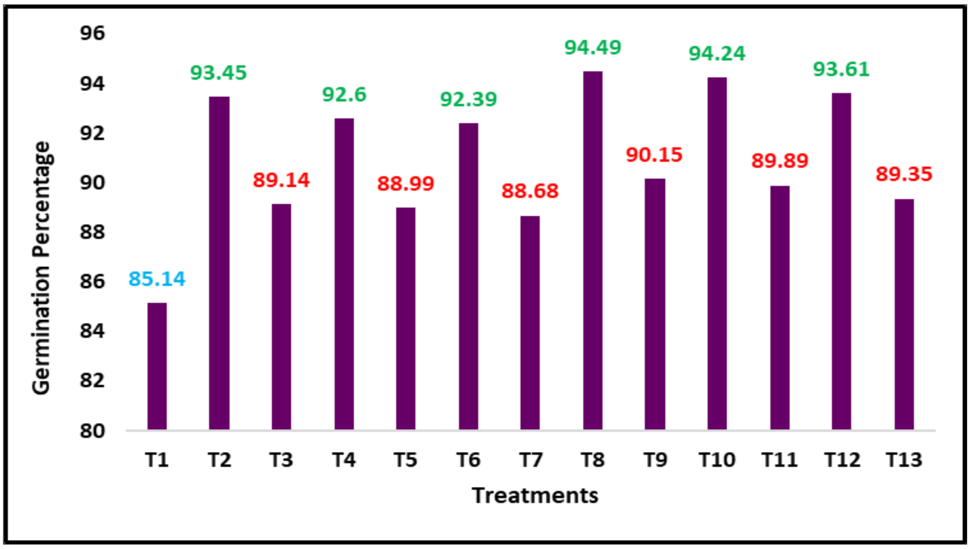

Fig. 1. Influence of seed hardening, soil and foliar nutrition on germination percentage of pearl millet under rainfed conditions.

Table 1. Influence of seed hardening, soil and foliar nutrition on plant height, LAI, dry matter production, ear head length and ear head girth of Pearl millet under rainfed conditions

Treatments	Plant height at harvest (cm)	LAI at 50 % flowering	Dry matter production at the harvest (kg ha^{-1})	Ear head length (cm)	Ear head girth (cm)
T_1	129.5	3.13	3056	27.65	5.98
T_2	161.8	4.08	4748	31.66	7.96
T_3	146.8	3.69	4113	30.19	7.48
T_4	157.8	4.04	4637	31.54	7.91
T_5	140.6	3.51	3851	29.52	7.28
T_6	152.3	3.86	4379	30.87	7.70
T_7	135.1	3.34	3574	28.84	7.07
T_8	194.5	5.01	6235	35.16	9.12
T_9	177.5	4.47	5438	33.09	8.46
T_{10}	189.0	4.84	5960	34.48	8.91
T_{11}	173.4	4.44	5279	33.01	8.39
T_{12}	183.0	4.66	5694	33.79	8.69
T_{13}	167.2	4.25	5029	32.34	8.18
SEm±	**1.78**	**0.04**	**64.21**	**0.21**	**0.05**
CD	**5.22**	**0.13**	**188.53**	**0.63**	**0.17**

Leaf area index at 50 % flowering stage

The maximum leaf area index of 5.01 was recorded in seed treatment with T_2+ foliar application of 19:19:19 @ 25 DAS (T_8). This treatment was followed by seed treatment with T_4+ foliar application of 19:19:19 @ 25 DAS (T_{10}) recorded the leaf area index of 4.84. The treatment T_1 control (No seed hardening and nutrient application) recorded a minimum leaf area index of 3.13.

Ear head length and girth

Among the various treatments experimented with, seed treatment with T_2+ foliar application of 19:19:19 @ 25 DAS (T_8) recorded the highest ear head length and ear head girth of 35.16 and 9.12 cm, respectively. This was followed by T_4+ foliar application of 19:19:19 @ 25 DAS (T_{10}) recorded the ear head length and ear head girth of 34.48 and 8.91 cm, respectively. The T_1 control (No seed hardening and nutrient application) registered the least ear head length and girth of 27.65 and 5.98 cm, respectively.

Harvest index

The data about the harvest index is presented in Fig 2. The harvest index was significantly influenced by the seed hardening, soil and foliar nutrition of pearl millet under rainfed conditions. Among the different treatments tested, T_2+ foliar application of 19:19:19 @ 25 DAS (T_8) recorded the highest harvest index of 34.50. This was followed by T_2+ foliar application of 19:19:19 @ 25 DAS (T_{10}) recorded the harvest index of 34.14. The treatment T_1 control (No seed hardening and nutrient application) registered the LAI of 29.37.

Discussion

Germination Percentage

Seed treatment with KCl enhances germination percentage, potentially due to increased hydration of colloids, higher viscosity and elasticity of protoplasm, increased bound water content, reduced water deficit and heightened metabolic activity (10). Seed hardening facilitated early emergence and boosted the total germination count and crop growth under soil moisture stress conditions. This improvement might be attributed to the uniform and early seedling emergence in the field, allowing the crop to better utilize available resources under stressful conditions. These findings are consistent with those of (11, 12).

Plant height and dry matter production at the harvest stage

Application of vermicompost improves the physical and biological properties of soil, including the supply of almost all the essential plant nutrients for the growth and development of pearl millet. It also provides secondary nutrients like Ca, Mg,

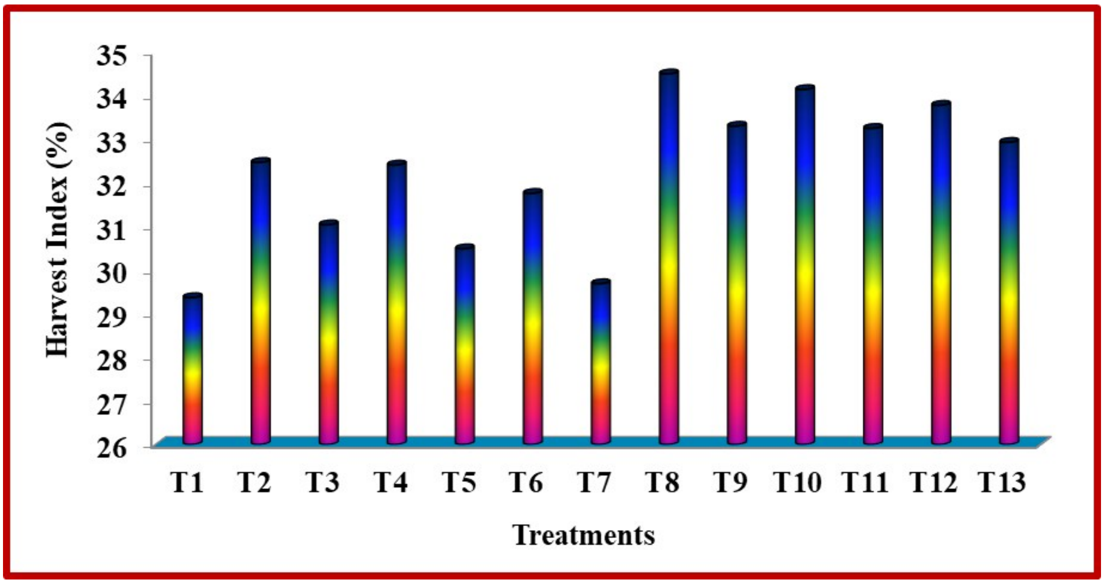

Fig. 2. Influence of seed hardening, soil and foliar nutrition on the harvest index (%) of pearl millet under rainfed conditions.

S and fairly high amounts of micronutrients to the plants. It increases cation exchange capacity, water holding capacity and phosphate availability in the soil. Thus, the balanced nutrient supply of macro and micronutrients to the soil due to the application of vermicompost under a favourable environment might have helped in the higher uptake of nutrients. This accelerated the growth of new tissues and the development of new shoots that have ultimately increased the plant height and dry matter accumulation of pearl millet. The results of the present investigation conform to those of (13-16).

The foliar application of 19:19:19 (NPK) could be considered the best way to reduce salt accumulation and maintain necessary fertility levels in the plant root zone and consequently improve plant height, plant metabolism and enhance plant meristematic activities of the crop and these results resembles early findings (17).

Leaf area index at 50 % flowering stage

The stimulative effect on foliar application of 19:19:19 (NPK) fertilizers on dry weight may be due to nitrogen being an essential element for building up protoplasm, amino acids and proteins, which induce cell division and initiate meristematic activity. Phosphorus is a part of the molecular structure of nucleic acid (DNA and RNA), the energy transfer compounds and phosphorus proteins. Moreover, potassium is very important in the overall metabolism of plant enzyme activity. It was found to serve a vital role in photosynthesis by directly increment in plant growth and leaf area, hence the CO_2 assimilation ratio in an excellent way. Potassium also has a beneficial effect on water consumption. The foliar fertilization of 19:19:19 (NPK) improved plant growth as fresh weight and dry weight, increased photosynthesis rate and increased the uptake of nitrogen, phosphorus and potassium elements. These are similar to early findings (18). Leaf area influenced the interception and utilization of solar radiation of crop canopies and consequently increased the dry matter production of pearl millet.

Ear head length and girth

Ear head length and ear head girth increased due to a sufficient supply of foliar application of 19:19:19 (NPK) to the pearl millet. NPK is an essential constituent of plant tissue and is involved in cell division and cell elongation. Foliar application of 19:19:19 (NPK) facilitates the production of more photosynthates, leading to increased ear head length and ear head girth. These are similar to previous works (19).

The significant improvement in leaf area index and dry matter production noticed at harvest stages would have resulted in enhanced ear head length and ear head girth. The findings are in line with the early results (20). Foliar application of 19:19:19 (NPK) fertilizers was found most beneficial in terms of better growth and increased yield components like ear head length and ear head girth of pearl millet under rainfed conditions. NPK absorbed by the plant is responsible for the fixation of a carbon skeleton to amino acid synthesis, which results in several proteins that have specific functions in plant metabolism.

Harvest index

Furthermore, vermicompost relatively added a large amount of macro and micronutrients especially phosphorus, calcium and magnesium which are involved in enzyme activities and impart physico-chemical and biological activities of soil resulting in more photosynthates assimilation and subsequent conversion of assimilates into yield attributes in a larger fraction which ultimately resulted in higher yield and the harvest index also increased. These findings confirm the earlier reports (21).

Conclusion

Based on the trend of harvest index, it was noticed that among the different treatments experimented, seed treatment with 2 % KCl + soil application of vermicompost @ 5 t ha^{-1} + foliar application of 19:19:19 @ 25 DAS (T_8) was superior for concerning germination percentage, plant height at harvest, leaf area index at 50 % flowering stage, dry matter production at harvest stage, ear head length and ear head girth of pearl millet under rainfed condition. Considering the above-mentioned facts, it can be concluded that seed treatment with 2 % KCl + soil application of vermicompost @ 5 t ha^{-1} + foliar application of 19:19:19 @ 25 DAS is a viable technology for enhancing the productivity of pearl millet under rainfed conditions.

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Authors' contributions

SM conducted the experiment, recorded data, performed data analysis and wrote the manuscript. KPS supervised the experiment, formulated the experimental design. SS contributed to manuscript corrections. KA, ES, AA, DG, SG, SMV and SK made corrections to the manuscript. All authors reviewed and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: The Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. Satyavathi CT, Ambawat S, Khandelwal V, Srivastava RK. Pearl Millet: A climate-resilient nutricereal for mitigating hidden hunger and providing nutritional security. Front Plant Sci. 2021;12:659938. https://doi.org/10.3389/fpls.2021.659938
2. FAO- International year of millets. Food and Agriculture Organization of the United Nations. 2023. https://www.fao.org/millets-2023/en/
3. Srimathi P, Sundaramoorthy S. Seed hardening - A review. Madras Agric J. 2000;87(7-9):370–3.
4. Jeyakumar P, Thangaraj M, Rajamani K. Organic seed priming in horticultural crops – A review. J Agric Technol. 2022;18(1):45–58.
5. Singh R, Gupta P. Effect of vermicompost on growth and yield of pearl millet under rainfed conditions. Int J Curr Microbiol Appl Sci. 2022;11(5):100–8. https://doi.org/10.20546/ijcmas.2022.1105.012
6. Gopal M, Gupta A. Soil microbial biomass and activity under different organic amendments. Agric Ecosyst Environ. 2001;86 (2):273–83. https://doi.org/10.1016/S0167-8809(00)00289-3
7. Chen Y, Aviad T. Effects of humic substances on plant growth. In: MacCarthy P, et al., editors. Humic Substances in Soil and Crop Sciences. Madison: ASA and SSSA; 1990:161–86.
8. Khan W, Rayirath UP, Subramanian S, Jithesh MN, Rayorath P, Hodges DM, et al. Seaweed extracts as biostimulants of plant growth and development. J Plant Growth Regul. 2009;28(4):386–99. https://doi.org/10.1007/s00344-009-9103-x
9. Fageria NK, Filho MPB, Moreira A, Guimaraes CM. Foliar fertilization of crop plants. J Plant Nutr. 2009;32(6):1044–64. https://doi.org/10.1080/01904160902872826
10. Farooq M, Wahid A, Ahmad N, Asad SA. Comparative efficacy of surface drying and de-drying seed priming in rice: Changes in emergence, growth and associated metabolic events. Paddy Water Environ. 2010;8:15-22. https://doi.org/10.1007/s10333-009-0170-1
11. Alam A, Amin N, Ara N, Ali M, Ali I. Effect of various sources and durations of priming in spinach seeds. Pak J Bot. 2013;45(3):773-7.
12. Sharma PK, Elouaer MA, Hannachi C. Seed priming to improve germination and seedling growth of safflower under salt stress. Eur J Biosci. 2017;6:76-84. https://doi.org/10.5053/ejobios.2012.6.0.9
13. Narolia RS, Poonia BL, Yadav RS. Effect of vermicompost and inorganic fertilizers on productivity of pearl millet (*Pennisetum glaucum*). Indian J Agric Sci. 2009;79(7):506-9.
14. Jadhav RP, Khafi HR, Raj AD. Effect of nitrogen and vermicompost on protein content and nutrient uptake in pearl millet (*Pennisetum glaucum* L.) R. Br. Emend Stuntz. Agric Sci Digest. 2011;31(4):319-21.
15. Choudhary R, Yadav LR, Parihar S. Studies on the interactive effect between vermicompost and fertility levels on pearl millet (*Pennisetum glaucum* L.). Ann Agri Bio Res. 2014;19(3):430-3.
16. Kumar P, Kumar R, Singh SK, Kumar A. Effect of fertility on growth, yield and yield attributes of pearl millet (*Pennisetum glaucum* L.) under rainfed conditions. Agriways. 2014;2(2):89-93.
17. Amanullah MM, Sekar S, Vincent S. Plant growth substances in crop production: A review. Asian J Plant Sci. 2010;9(4):215-22.
18. Hu Y, Burucs Z, Schmidhalter U. Effect of foliar fertilization application on the growth and mineral nutrient content of maize seedling under drought and salinity. Soil Sci Plant Nutr. 2008;54 (1):133-41. https://doi.org/10.1111/j.1747-0765.2007.00224.x
19. Rasheed M, Hussain A, Mahmood T. Growth analysis of hybrid maize as influenced by planting techniques and nutrient management. Int J Agrl Biol. 2003;5(2):169-71.
20. Sunitha N, Reddy M. Effect of graded nutrient levels and timing nitrogen application on yield and quality of sweet corn (*Zea mays* L.). Madras Agric J. 2012;99(4-6):240-3. https://doi.org/10.29321/MAJ.10.100055
21. Elfstrand S, Bath B, Martensson A. Influence of various forms of green manure amendment on soil microbial community composition, enzyme activity and nutrient levels in leek. Appl Soil Ecol. 2007;36:70-82. https://doi.org/10.1016/j.apsoil.2006.11.001

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