Effects of Micronutrients (Mn and Zn) Fertilizer on the Growth and Production of Sorghum (Sorghum bicolor L.)

10.18196/pt.v11i2.15998

Siti Fatimah Batubara[1*], Novia Chairuman[1], Vivi Aryati[1], Deddy Romulo Siagian[2]

[1]*Research Center for Food Crops, Research Organization for Agriculture and Food, National Research and Innovation Agency (BRIN), Cibinong Science Center, Jl. Raya Jakarta-Bogor km 46, Cibinong, Bogor, West Java 16911, Indonesia*

[2]*Research Center for Horticulture and Estate Crop, Research Organization for Agriculture and Food, National Research and Innovation Agency (BRIN), Cibinong Science Center, Jl. Raya Jakarta-Bogor km 46, Cibinong, Bogor, West Java 16911, Indonesia*

[*]*Corresponding author, email:* sifa.cha@gmail.com

ABSTRACT

Micronutrients Mn and Zn are essential elements required in trace amounts, although they play an important role in plant growth. This study aimed to investigate the impact of manganese (Mn) and zinc (Zn) fertilizer on growth and productivity of sorghum. This study was conducted in farmer's field at Pasar 6 Kwala Mencirim Village, Sei Bingai District, Langkat Regency, North Sumatera started in December 2020 until April 2021. A non-factorial randomized block design with eight treatments and four replications was used, consisted of control (without fertilizer), 100% N, P, K (local fertilizer recommendation), and the level of Mn and Zn fertilizer combined with 75% and 50% dose of N, P, K fertilizer. Measurements were taken for plant height and plant production. The data was analyzed using ANOVA and DMRT at a significance level of 5%, and RAE equation. This study showed that Mn and Zn fertilizers significantly affected sorghum growth and production. The highest productivity was 4770 kg ha-1, while the control was 2260 kg ha-1. This study concluded that applying 1 dose Mn and Zn fertilizer combined with 75% N, P, K increase the yields and reduces 25% the use of N, P, K fertilizers in sorghum field.

Keywords: Fertilizer; Micronutrients; Sorghum; Yield

ABSTRAK

Unsur hara mikro Mn dan Zn merupakan hara penting yang dibutuhkan dalam jumlah kecil, meskipun unsur-unsur tersebut sangat berperan dalam siklus hidup tanaman. Tujuan penelitian ini adalah untuk mengetahui pengaruh pupuk mangan (Mn) dan seng (Zn) pada pertumbuhan dan produkt6itas sorgum. Dilaksanakan di lahan petani di Desa Pasar 6 Kwala Mencirim, Kecamatan Sei Bingai, Kabupaten Langkat, Sumatera Utara mulai bulan Desember 2020 sampai April 2021. Rancangan acak kelompok non faktorial dengan delapan perlakuan dan empat ulangan dilakukan pada penelitian ini, yaitu kontrol (tanpa pupuk), 100%. N, P, K (rekomendasi pemupukan setempat), dan taraf pupuk Mn dan Zn dikombinasikan dengan dosis pupuk N, P, K 75% dan 50%. Pengukuran dilakukan pada parameter tinggi tanaman dan produksi tanaman. Data dianalisis menggunakan ANOVA dan DMRT pada taraf signifikansi 5%, dan perhitungan RAE. Hasil penelitian memperlihatkan bahwa pupuk Mn dan Zn berpengaruh nyata pada pertumbuhan dan produksi sorgum. Produktivitas tertinggi 4770 kg ha-1, sedangkan kontrol 2260 kg ha-1. Penelitian ini menyimpulkan bahwa pemberian pupuk Mn dan Zn 1 kali dosis yang dikombinasikan dengan N, P, K 75% meningkatkan hasil dan mengurangi 25% penggunaan pupuk N, P, K pada lahan sorgum.

Kata kunci: *Pemupukan; Unsur hara mikro; Sorgum; Produksi*

INTRODUCTION

Sorghum is a predominantly rainfed crop where the yield depends on drought resistance. Soil moisture between 25% - 50% during field capacity germination ranges is the ideal sorghum condition. According to Mundia et al. (2019), several factors that affect sorghum production include climate, agricultural supplies, biodiversity, population, demand for other food crops, price level, culture, and armed. Production of ratoon is also affected by plant spacing and plant population (Azizah et al., 2022), while research by Suwardi & Suwarti (2020) reported that the dose and timing of ZA fertilizer application had an expressive impact on growth and production of sweet sorghum Super 1 variety.

Mn has an important role for plant life cycle even though it is only needed in small amounts (Alejandro et al., 2020). Mn acts as an enzyme co-factor, and as a key in enzyme-catalyzed reactions. It

Article History
Received: 26 August 2022
Accepted: 26 July 2023

is crucial for photosynthesis reactions, plays a role in oxygen evolution during photosynthesis, and is essential for root growth. Lignin synthesis also depends on Mn to add strength and stiffness to cell walls (Liu et al., 2018). Mn is very influential on the yield and grain quality (Andresen et al., 2018).

Mn availability for plants in the soil is deficient from about 20 to 3,000 ppm (0.002 to 0.30 percent). Mn^{2+} is the available form in soil solution and often complexed by organic compounds. The average concentration of Mn in plants usually ranges from 20 to 300 ppm and falls below 15 to 20 ppm in deficiency conditions. For the sorghum plant, the Mn sufficiency range is 18-190 ppm. Mn deficiency usually occurs in alkaline soils with a decrease of 100 times for every 1 unit increase in pH (Seran, 2017). On other extremes, Mn can be toxic to the sensitive plant when soil pH is too low (<5) (Alejandro et al., 2020).

Zinc is essential in photosynthesis, metabolism, protein synthesis, protection from heat stress conditions (Cabot et al., 2019), and biomass production (Datcu et al., 2019). Zn and Fe improve kernel number and weight in maize (Liu et al., 2020). A deficiency of Zn affects plant growth and function, impacting human nutrition (Hacisalihoglu, 2020).

Sorghum productivity in Indonesia varies, and it is still deficient at the farmer's level of about 1.5 - 3 t ha^{-1} (Lestari et al., 2019). To achieve optimal grain production, sorghum necessitates sufficient nutrient availability, necessitating appropriate fertilization practices. One potential strategy for enhancing cereal crop productivity is optimizing the utilization of essential nutrients, including micronutrients. The levels of macro and micronutrient requirements in sorghum are K > N > Ca > Mg > S > P > Fe > Zn > Mn > Cu. Combining the use of macronutrients and micronutrients increases sorghum yields and N, P and K uptake, as well as nutrient use efficiency. In addition to N, P, and K, Zn is the most frequently limiting sorghum growth and production (Cavalcante et al., 2018; Weldegebriel et al., 2018).

The growth and production of sorghum can be enhanced by applying foliar Mn and Zn, as the presence of plant micronutrients is significantly controled by soil factors such as pH and nutrient content. This research was held to (i) determine the effects of micronutrient (Mn and Zn) fertilizer on the growth and productivity of sorghum and (ii) obtain the optimum dose of micronutrient (Mn and Zn) fertilizers on sorghum.

MATERIALS AND METHODS

Study Site

This study was managed in the 1000 m^2 farmer's field at Pasar 6 Kwala Mencirim Village, Sei Bingai District, Langkat Regency, North Sumatera (Latitude: $3^0$52'72.9" N, Longitude: $98^0$48'74.4" E and 60.8 m above sea level). Langkat Regency has a Wet Tropical Climate, where rainfall above 100 mm^3/month without a dry month (throughout year is a wet month). The average monthly rainfall in the study site was 297.08 mm/month (BPS, 2021).

Soil Analysis

Soil chemical analysis was held in the laboratory of soil, plant, fertilizer, and water at North Sumatera Assessment Institute for Agricultural Technology (AIAT), including analysis of pH H_2O_2:5 using a pH glass electrode, total nitrogen (N) using the Kjeldahl destillation method, phosphorus (P) availability using the Bray I, soil C content using the Walkley and Black method, exchangeable K, Ca, and Mg using NH_4 Acetat 1 N, pH 7, total Cu, Zn, Mn, and Fe using HNO_3, Cation Exchange Capacity (CEC) using direct destillation, and soil texture using a hydrometer (Balai Penelitian Tanah, 2012).

Table 1. Doses of Micronutrients Fertilizer

Treatments	Dose of micronutrients fertilizer (g L^{-1})	Dose of micronutrients fertilizer (L ha^{-1})	Dose of inorganic fertilizer (kg ha^{-1})		
			Urea	SP36	KCl
P0 (Control)	0	0	0	0	0
P1(100% N, P, K)	0	0	200	100	100
P2 (50% micronutrient f. + 75% N, P, K f.)	2.5 ml L^{-1}	5 L ha^{-1}	150	75	75
P3 (100% micronutrient f. + 75% N, P, K f.)	5 ml L^{-1}	10 L ha^{-1}	150	75	75
P4 (150% micronutrient f. + 75% N, P, K f.)	7.5 ml L^{-1}	15 L ha^{-1}	150	75	75
P5 (50% micronutrient f. + 50% N, P, K f.)	2.5 ml L^{-1}	5 L ha^{-1}	100	50	50
P6 (100% micronutrient f. + 50% N, P, K f.)	5 ml L^{-1}	10 L ha^{-1}	100	50	50
P7 (150% micronutrient f. + 50% N, P, K f.)	7.5 ml L^{-1}	15 L ha^{-1}	100	50	50

Research Design

A non-factorial randomized complete block design with 8 treatments and 4 replications was used, resulting in 32 experimental units. The micronutrient doses were 10 L ha^{-1}, and the local fertilizer recommendation was 200 kg ha^{-1} urea, 100 kg ha^{-1} SP36, and 100 kg ha^{-1} KCl. The treatments consisted of P0 (control) (without fertilizer), P1 (100% local fertilizer recommendation), P2 (0.5 doses of micronutrient fertilizer + 75% dose of local fertilizer recommendation, P3 (1 dose of micronutrient fertilizer + 75% dose of local fertilizer recommendation) P4 (1.5 doses of micronutrient fertilizer + 75% dose of local fertilizer recommendation, P5 (0.5 doses of micronutrient fertilizer + 50% dose of local fertilizer recommendation), P6 (1 dose of micronutrient fertilizer + 50% dose of local fertilizer recommendation), and P7 (1.5 dose of micronutrient fertilizer + 50% doses of local fertilizer recommendation) (Permentan No 36, 2017). The number of replications was set using the formula (p-1) (u-1) $\geq$ 15.

By spraying it on the leaves, micronutrient fertilizer was given at 10, 20, 30, and 40 DAP (4 times during the growing season). Micronutrient fertilizer was dissolved in water. The volume of water was 500 L ha^{-1}. Urea, SP36, and KCl as standard fertilizers were given 7 and 30 days after planting (DAP). The fertilizer doses are shown in Table 1.

Data Analysis

The effects of fertilizers treatment were determined with Analysis of Varian (ANOVA) and followed by DMRT test at a 5% significant level to ensure the significant impact of treatments on the plant growth and production. Relative Agronomy Effectiveness (RAE) was used to obtain the micronutrient Mn and Zn fertilizer Effectiveness (Matckay et al., 1984).

RESULTS AND DISCUSSION

Soil characteristic

The soil in the research location before treatments indicated an acidic soil pH of 4.76, very high organic carbon (organic C) content, high total nitrogen, low availability of phosphorous (P) and potassium (K), low level of calcium (Ca) and magnesium (Mg) content, sufficient of micronutrient content, and sandy loam soil texture (Table 2).

Concentration of H^+ ions in the soil solution (pH), which affects many reactions in the soil and is essential for the chemistry and fertility of the

Table 2. Soil Physical and Chemical Characteristic before Experiment

Type of Analysis	Value	Criteria
Organic Carbon (%)	5.24	Very high
Total Nitrogen (%)	0.54	Very high
Available P (ppm)	6.56	Low
Exc-K (me/100 g)	0.13	Low
pH	4.76	Acid
Exc-Al (me/100 g)	1.41	Very low
Ca (me/100 g)	3.35	Low
Mg (me/100 g)	0.66	Low
Cu (ppm)	4	Sufficient
Zn (ppm)	5	Sufficient
Mn (ppm)	24	Sufficient
Fe (ppm)	32	Sufficient
Texture		
Sand (%)	75.31	-
Silt (%)	22.22	-
Clay (%)	2.47	-
CEC (me/100 g)	28.77	High

soil, including nutrient availability, cation exchange capacity, and also biogeochemical and physical in the soil (Neina, 2019). The availability of P and Mg decreased at pH below 5.5, while Al, Mn, and Cu increased to toxic levels.. The interaction of P and Al elements forms a complex that limits the availability of P (Omenda et al., 2021). This condition follows the soil analysis results at the research site before planting, where the soil pH was under 5.5, and the P, K, Ca, and Mg nutrients were low. The dominant soil texture is sandy. With this soil texture, the cation exchange capacity is usually low at around 1-8 meq $100g^{1}$; however, the CEC in the soil of the research location was 28.77 meq $100g^{1}$, where this CEC value is usually found in clay or loamy soils.

However, with organic C content, which also has very high criteria of 5.24%, this is understandable, where there may be sufficient addition of organic matter into the soil before the research was carried out. In sandy soil, the ability to bind nutrients is low due to the low water-holding capacity, so the nutrients will be easily lost due to leaching from the soil solution. Although plants require micronutrients in relatively very small amounts for maximum growth and production, their deficiency can cause major disturbances in plants' physiological and metabolic processes. The availability of nutrients in the soil is controled by many factors, including micronutrients, causes the provision of micro-nutrient fertilizers on cultivated land cannot meet the needs of plants for root development and nutrient utilization. The application of fertilizer through a foliar sprays, resulting in nutrient absorption through foliage and nutrient supply at the vegetative and flowering stages of plant growth (Azis et al., 2019).

Plant height (cm)

Sorghum plants are 95 days old after germination or more, depending on the variety. There were significant differences between treatments based on analysis of variance on plant height (cm) at the 4, 6, and 8 weeks after planting (WAP). (Table 3).

This result showed that the micronutrient fertilizer of Mn and Zn through the foliar application impactfully enhanced plant height in comparison with the control treatment and one hundred percent N, P, and K fertilizer without micronutrient fertilizer. Sadeghi et al. (2021) confirmed that applying Zinc and Magnesium fertilizer gave better germination, plant height, and number of tillers on wheat. Foliar application of Mn will minimize interaction with soil particles and decrease chemical fixation to supply sufficient Mn to overcome Mn deficiency (Rashed et al., 2019). In addition, Li et al. (2017) stated that foliar Mn application was only effective for a limited period because Mn moved very little in the plant and did not move from old leaves to young leaves that were deficient in Mn.

The highest plant height in this research resulted in the treatment of 10 L ha^{-1} Mn and Zn fertilizer

Table 3. Effects of Micronutrients (Mn and Zn) Fertilizer on Plant Height of Sorghum at 4, 6, and 8 Weeks After Planting (WAP)

Code	Plant height (cm)		
	4 WAP	6 WAP	8 WAP
P0	30.5a	82.0a	215.5a
P1	41.8b	107.5b	222.5b
P2	44.0b	125.0c	226.3b
P3	49.3b	118.8b	235.3c
P4	48.5b	120.3c	234.5c
P5	46.8b	116.0b	227.8c
P6	45.5b	117.0b	228.8c
P7	48.5b	129.0c	230.0c

Note: Means followed by the same letters are non-significant (ANOVA α = 5%).

with a 75% dose of N, P, and K fertilizer. This result showed that applying Mn and Zn fertilizers significantly affected plant height and minimized using N, P, and K fertilizers. As a nutrient that plays an enzyme cofactor (Andresen et al., 2018), sorghum needs Mn for growth and production. In a photosynthetic organism, Mn acts in photosystem II as an essential element of the metalloenzyme cluster of the oxygen-evolving complex (OEC). Meanwhile, Zn catalyzes many metabolic reactions that have roles in plant resistance to disease, cell membrane integrity, pollen formation, protein synthesis, and increased levels of antioxidant enzymes (Jerlin et al., 2017).

Sorghum production

There were substantial contrasts among treatments based on the analysis of variance in sorghum production. Micronutrients Mn and Zn fertilizer application significantly affected sorghum production compared to the control and standard treatment (100% dose of N, P, K fertilizer). Treatment of P1 was not significantly different from P2. However, these treatments showed significantly different results for P3, P4, P5, P6, and P7.

Sorghum production showed a similar figure with plant height. The highest production of sorghum in this research of 4770 kg ha^{-1} was higher than the average sorghum productivity in Indonesia, between 1.67 tons/ha and 2.73 tons/ha, even higher than the productivity of sorghum in Kupang, East Nusa Tenggara Province, which is only 0.55 tons/ha to 1.1 tons/ha (Lestari et al., 2019). Different varieties with different yield potentials, soil types, nutrient availability, and fertilizer application to plants can cause this variation in sorghum production. From 1970 to 2012, the Indonesian government released 11 sorghum varieties with a potential 6 tons/ha yield. Meanwhile, the Super 2 sorghum variety used in this study was released in 2013 with a potential productivity of 6.3 tons ha^{-1}. With the results get in this study of 4.7 tons/ha compared to the potential yield of 6.3 tons ha^{-1}, this result is good enough compared to production at the farm level. Research by Miner et al. (2022) on wheat plants reported that the sufficiency of micronutrient availability in soil increased yield and grain nutrition.

From this study, the results reported that the treatment of 10 L ha^{-1} of micronutrient and 75% dose of N, P, K fertilizer could increase production by 57.9% compared to 100% dose of N, P, K fertilizer application. Meanwhile, sorghum production between the treatment of micronutrients Mn and Zn fertilizer with inorganic fertilizer significantly differed between treatments P2, P3, P4, P5, P6, and P7. This result showed that micronutrients Mn and Zn greatly affected the sorghum yield, while Mn is required for the activity of enzymes, oxygen evolution of photosynthesis, and auxin catabolism. According to Choudary et al. (2017), micronutrients application through the soil and foliar application can improve nutrient (N, P, K, Zn, Fe, dan B) uptake by 14.12%, 11.75%, 13.98%, 10.86%, 12.33%, and 9.57%, respectively, and combination of NPK fertilizer with Mn and Zn

Table 4. Effects of Micronutrients (Mn and Zn) Fertilizer on Sorghum Production (kg ha^{-1}) and Increased Production (%)

Treatment	Production (kg ha^{-1})	Increased production compared to 100% dose of N, P, K fertilizer (P1) (%)
P0	2260a	-
P1	3020b	-
P2	3480b	15.2
P3	4770d	57.9
P4	4440c	47.0
P5	3740c	23.8
P6	3910c	29.5
P7	3850c	27.5

Note: Means followed by the same letters are non-significant (ANOVA α = 5%)

fertilizer provides a couple of benefits, such as increasing the production and improving the quality of the grain nutrition. The research by Giridhar et al. (2021) on sorghum reported that soil rich in Zinc would increase sorghum yield and dry matter. The effects of micronutrients Mn and Zn fertilizer on sorghum production are shown in Table 4.

Relative Agronomy Effectiveness (RAE)

The RAE values of the micronutrients Mn and Zn fertilizer treatments (P2, P3, P4, P5, P6, and P7) were higher than 95%, which means that the micronutrients fertilizer effectively influences the production of sorghum. The results of RAE for all treatments are shown in Table 5.

The result of Relative Agronomy Effectiveness (RAE) showed that P3 treatment with the application of 10L ha^{-1} micronutrient Mn and Zn combined with a 75% dose of N, P, K fertilizer had the highest RAE value of 330%, meaning that the application of micronutrient Mn and Zn fertilizer was effective to increase the yield and reduce the N, P, K fertilizer doses up to 25%. The application of Mn and Zn fertilizer with 50% of the recommended dose of N, P, K fertilizer as in the treatment P5 (5 L ha^{-1} Mn and Zn fertilizer + 50% dose of local fertilizer recommendation), P6 (10 L ha^{-1} Mn and Zn fertilizer + 50% dose of local fertilizer recommendation), and P7 (15 L ha^{-1} Mn and Zn fertilizer + 50% dose of local fertilizer recommendation) was also effective in increasing sorghum production compared to control and 100% N, P, K treatments with the RAE value of 195%, 217%, and 209%, respectively. An effective fertilizer goes the maximum plant response at the lowest application cost. Research by Choudhary et al. (2017) reported that the combined application of micronutrients with N, P, and K fertilizers increased the yield by 25.33% and improved the quality of grain nutrition. Gureev (2021) also reported that a combination of seed treatment and micronutrient fertilizer through foliar application increased the economic efficiency of winter wheat production. The increase in yields addresses the fact that higher nutrient absorption by the plant is due to the increased photosynthetic efficiency and assimilation production (Choudhary et al., 2017).

Table 5. Relative Agronomy Effectiveness (RAE)

Treatment	RAE Value (%)
P0	-
P1	-
P2	161
P3	330
P4	287
P5	195
P6	217
P7	209

The Effectiveness of Mn and Zn fertilizer in this research was also supported by soil pH, where the soil pH was acidic, and the availability of Mn and Zn was sufficient for sorghum plants. For the low P and K nutrients, phosphorous and potassium fertilizers have been added as plant requirements. Coupled with Mn and Zn fertilizer application through the foliar application, the growth and yield of sorghum were getting better.

In addition to increasing production, the foliar application of micronutrients Mn and Zn can also be used to improve the Zn content in the grain, called biofortification (Azis et al., 2019). The process of biofortification to increase nutrient concentration in crops can be done through agronomic biofortification with fertilization and genetic biofortification through plant breeding. From an agronomic perspective, sowing seeds with high Zn content in Zn-deficient soils can increase growth and yield through better germination, seedling vigor, and stress tolerance. The study of biofortification on wheat and rice resulted in the application of Zn fertilizer being significantly effective in increasing grain Zn content (Cakmak & Kutman, 2018).

CONCLUSIONS

This study concluded that applying micronutrient (Mn and Zn) fertilizers affect the growth and yields of sorghum and reduces the use of N, P, and K fertilizers. P3 treatment (10 L ha^{-1} Mn and Zn combined with 75% dose of N, P, K fertilizer) was the most effective in increasing the growth and yield and reducing 25% application of N, P, K fertilizer in sorghum fields.

ACKNOWLEDGMENTS

We would like to thank CV. Raja Grafika that have provided financial assistance for this research, and to the farmers in the research location during the field works. For laboratory facilities, we thank North Sumatra AIAT and all the laboratory staff who have assisted the analysis process.

REFERENCES

Alejandro, S., Holler, S., Meier, B., & Peiter, E. (2020). Manganese in Plants: From Acquisition to subcellular Allocation. Frontiers in Plant Science, 11, 517877. https://doi.org/10.3389/fpls.2020.00300

Andresen, E., Peiter, E., & Kupper, H. (2018). Trace metal metabolism in plants. Journal of Experimental Botany, 69(5), 909-954. https://doi.org/10.1093/jxb/erx465

Azis, M. Z., Yaseen, M., Abbas, T., Naveed, M., Mustafa, A., Hamid, Y., Saeed, Q., & Xu, M. G. (2019). Foliar application of micronutrients enhances crop stands, yield and the biofortification essential for human health of different wheat cult6ars. Journal of Integrat6e Agriculture, 18(6), 1369-1378, https://doi.org/10.1016/S2095-3119(18)62095-7

Azizah, N., Zubaidi, A., & Supeno, B. (2022, June). Pertumbuhan dan Hasil Tanaman Ratun Sorgum (Sorghum bicolor L. Moench) Terhadap Perlakuan Jarak Tanam dan Jumlah Tanaman Per Rumpun. Prosiding Seminar Nasional Fakultas Pertanian UNS, 6(1), 264-273.

Balai Penelitian Tanah. (2012). Petunjuk teknis analisis kimia tanah, tanaman, air dan pupuk. Badan Penelitian dan Pengembangan Pertanian. Departemen Pertanian.

BPS. (2021). Kabupaten Langkat dalam angka. Badan Pusat Statistik.

Cabot, C., Martos, S., Llugany, M., Gallego, B., Tolrà, R. & Poschenrieder, C. (2019). A role for zinc in plant defense against pathogens and herb6ores. Frontiers in Plant Science, 10, 1171. https://doi.org/10.3389/fpls.2019.01171

Cakmak, I., & Kutman, U. B. (2018). Agronomic biofortification of cereals with zinc: a review. European Journal of Soil Science, 69, 172-180. https://doi.org/10.1111/ejss.12437

Cavalcante, T.J., Castoldi, G., Rodrigues, C.R., Nogueira, M.M., & Albert, A.M. (2018). Macro and micronutrients uptake in biomass sorghum. Pesquisa Agropecuária Tropical, 48(4), 364-373. https://doi.org/10.1590/1983-40632018v4851874

Choudhary, S.K., Jat, M.K., & Mathur, A.K. (2017). Effect of micronutrient on yield and nutrient uptake in sorghum. Journal of Pharmacognosy and Phytochemistry, 6(2), 105-108.

Datcu, A. D., Alexa, E., Ianovici, N., & Sala, F. (2019). Zinc fertilization effect on biomass, production and some morphometric parameters for wheat. Research Journal of Agricultural Science, 51(3), 93-98.

Giridhar, K., Gowda, N. K. S., Pal, D. T., Krishnamoorthy, P., Joseph, R. F., Dey, D. K. & Shukla, A. K. (2021). Feeding zinc bio enriched sorghum stover decreases zinc deficiency in sheep. Indian Journal of Animal Sciences, 91(4), 299–304. https://doi.org/10.56093/ijans.v91i4.114338

Gureev, I. (2021). The use of micronutrient fertilizers in the cult6ation of winter wheat. BIO Web of Conferences, 32, 02003. https://doi.org/10.1051/bioconf/20213202003

Hacisalihoglu, G. (2020). Zinc (Zn): The last nutrient in the alphabetand shadding light on Zn efficiency for the future of crop production under suboptimal Zn. Plants, 9, 1471, https://doi.org/10.3390/plants9111471

Jerlin, B., Sharmila, S., Kathiresan, K., & Kayalvizh, K. (2017). Zinc solubilizing bacteria from rhizospheric soil of mangroves. International Journal of Microbiology and Biotechnology 2(3), 148-155. https://doi.org/10.11648/j.ijmb.20170203.17

Omenda, J. A., Ngetich, K. F., Kiboi, M. N., Mucheru-Muna, M. W., & Mugendi, D. N. (2021). Phosphorus availability and exchangeable aluminum response to phosphate rock and organic inputs in the Central Highland of Kenya. Heliyon, 7(3), e06371, https://doi.org/10.1016/j.heliyon.2021.e06371

Lestari, R., Rachmandiyanto, A.R., & Magandi, M. (2019). Sorghum cult6ation, production, and utilization at Kupang district of Nusa Tenggara Timur, Indonesia. Proceedings The SATREPS conference, 2(1),146-153.

Li, C., P. Wang, N. W. Menzies, E. Lombi & Kopittke, P. M. (2017). Effects of changes in leaf properties mediated by methyl jasmonate on foliar absorption of Zn, Mn and Fe. Annals of Botany, 120(3), 405-415. https://doi.org/10.1093/aob/mcx063

Liu, Q., Luo, L., & Zheng, L. (2018). Lignins: Biosynthesis and biological functions in plants. International Journal of Molecular Sciences, 19(2), 335. https://doi.org/10.3390/ijms19020335

Liu, D.Y., Zhang, W., Liu, Y. M., Chen, X.P., & Zhou, C.Q. (2020). Soil application of Zinc fertilizer increases maize yield by enhancing the kernel number and kernel weight of inferior grains. Frontiers in plant science, 11, 188. https://doi.org/10.3389/fpls.2020.00188

Matckay, A.D., Syers, J.K., & Gregg, P.E.H. (1984). The ability of chemical extraction procedures to assess the agronomic Effectiveness of phosphate rock material. New Zealand Journal of Agricultural Research, 27, 219-230. https://doi.org/10.1080/00288233.1984.10430424

Miner, G. L., Delgado, J. A., Ippolito, J. A., Johnson, J. J., Kluth, D. L., & Stewart, C. E. (2022). Wheat grain micronutrients and relationships with yield and protein in the US Central Great Plains. Field Crops Research, 279, 108453. https://doi.org/10.1016/j.fcr.2022.108453

Mundia, C. W., Secchi, S., Akamani, K., & Wang, G. (2019). A regional comparison of factors affecting global sorghum production: The case of North America, Asia, and Africa's Sahel. Sustainability, 11, 2135, https://doi.org10.3390/su11072135

Neina, D. (2019). The role of soil pH in plant nutrition and soil remediation. Applied and Environmental soil science. https://doi.org/10.1155/2019/5794869

Permentan No. 36. (2017). Tentang pendaftaran pupuk organik. Kementerian Pertanian Republik Indonesia

Rashed, M. H., Hoque, T. S., Jahangir, M. M. R., & Hashem, M. A. (2019). Manganese as a micronutrients in agriculture: Crop requirement and management. Journal of Environmental Science and Natural Resources, 12(1-2), 225-242. https://doi.org/10.3329/jesnr.v12i1-2.52040

Sadeghi, F., Rezeizad, A., & Rahimi, M. (2021). Effect of Zinc and Magnesium fertilizers on the yield and some characteristic of wheat (Triticum aest6um L.) seeds in two years. International Journal of Agronomy, 2021, 1-6. https://doi.org/10.1155/2021/8857222

Seran, R. (2017). Pengaruh mangan sebagai unsur hara mikro esensial terhadap kesuburan tanah dan tanaman. Bio-Edu: Jurnal Pendidikan Biologi, 2 (1), 13-14.

Suwardi, & Suwarti. (2020). Pertumbuhan dan produksi sorgum manis Super-1 pada waktu aplikasi dan dosis pupuk ZA. Jurnal Pertanian Terpadu, 8(2), 175-188. https://doi.org/10.36084/jpt..v8i2.245

Weldegebriel, R., Araya, T., & Egziabher, Y. G. (2018). Effect of NPK and blended fertilizer application on nutrient uptake and use efficiency of selected sorghum (Sorghum bicolor (L.) Moench) varieties under rainfed conditions in Sheraro District, Northern Ethiopia. Momona Ethiopian Journal of Science, 10 (1), 140-156. https://doi.org/10.4314/mejs.v10i1.10