South African Journal of Botany 182 (2025) 272–279

Contents lists available at ScienceDirect

South African Journal of Botany

journal homepage: www.elsevier.com/locate/sajb

River grass organic and different colored plastic mulch effects on growth, yield, and quality of *Moringa oleifera* Lam

Asanda Sokombela[a], Ashwell R. Ndhlala[a,*], Moshibudi P. Bopape-Mabapa[a], Bahlebi K. Eiasu[b]

[a] *Department of Plant Production, Soil Science and Agricultural Engineering, University of Limpopo, Private Bag X 1106, Sovenga 0727, South Africa*
[b] *Department of Agronomy, University of Fort Hare, Private Bag X1314, Alice 5700, South Africa*

ARTICLE INFO

Article History:
Received 5 February 2025
Revised 5 April 2025
Accepted 6 May 2025
Available online xxx

Edited by Dr Olaoluwa Omoniyi Olarewaju

Keywords:
Climate-smart
Food security
Malnutrition
Moringa
Plastic mulching

ABSTRACT

Food insecurity in Africa is aggravated by land degradation, climate change, and water scarcity, exacerbating the declining crop productivity. *Moringa oleifera* Lam., known for its nutritional benefits and versatility, could be a promising solution to address food insecurity and malnutrition in South Africa. A study was conducted to evaluate the effects of various mulches on moringa growth, yield, and quality. The experiment used a randomized complete block design with six mulch treatments, replicated four times: (1) no mulch, (2) plant residues mulch, (3) red plastic mulch, (4) black plastic mulch, (5) green plastic mulch, and (6) white plastic mulch. Results showed that black plastic mulch significantly improved moringa growth and nutrient composition, with the highest values for plant height (292 cm), stem diameter (72 mm), chlorophyll content (75 spad units), biomass (1.84 kg/plot), and key nutrients: ash (14.93 %), fat (4.92 %), ADF (29.87 %), NDF (42.99 %), and crude protein (27.93 %). Black plastic also enhanced macro-nutrient levels such as phosphorus (80 %), nitrogen (3.8 %), calcium (3.32 %), magnesium (59 %), and potassium (1.8 %). Additionally, it increased manganese (149 mg/kg), iron (125 mg/kg), aluminum (71.25 mg/kg), and zinc (22.45 mg/kg) compared to other mulches. In contrast, red plastic mulch had higher sodium levels (1387 mg/kg), and green and white plastics performed the worst. Black plastic mulch proved to be the most effective in promoting moringa growth and enhancing its nutritional value. This suggests that plastic mulching could be a viable strategy for improving food security and addressing challenges related to soil degradation, climate change, and water scarcity.

1. Introduction

The increasing demand for utilization of traditional medicine is progressively influencing the population dynamics of certain plant species within their native habitats (Chen et al., 2019; Khan et al., 2025). Harvesting wild medicinal plants is an essential economic activity for rural communities and may reduce poverty and malnutrition (Groner et al., 2022). However, a combination of high harvesting frequency and climate change significantly accelerates the decline and potential extinction risk of certain plant species utilized in traditional medicine (Hopping et al., 2018). Therefore, smallholder farmers' production of *Moringa oleifera* (moringa) in rural communities is essential due to its substantial economic and nutritional benefits, which help mitigate food insecurity and malnutrition (Sokombela et al., 2022; Khan et al., 2025). The production and utilization of moringa by smallholder farmers in South Africa are hampered by the lack of knowledge about its potential benefits (Moyo et al., 2011), growth habits, silvicultural management practices, and seed availability (Gadzirayi et al., 2013). However, smallholder farmers face challenges in moringa production, particularly with weed management, due to the plant's slow germination and growth characteristics (Gadzirayi et al., 2013). To enhance moringa production in rural communities, it is vital to implement optimized agronomic practices that maximize yield potential and improve the nutritional profile of the crop.

Mulching has been identified as a potential strategy to enhance crop performance and control weeds (Singh et al., 2021). It influences soil moisture, temperature, and fertility and impacts plant growth and phytonutrient content (Lee and Thierfelder, 2017). Smallholder farmers use organic materials as mulching material to enhance crop yields with minimal environmental adverse effects (Raman et al., 2018). Besides reducing soil loss, improving soil fertility, and crop yields, organic mulching has, however, been found to have detrimental effects on the ecosystem and environment by increasing pest incidence and promoting greenhouse gas (GHG) emissions (Daryanto et al., 2018; Nyambo et al., 2020a). Furthermore, adverse effects of surface residue retention on crop performance have been attributed to nitrogen immobilization, waterlogging, and decreased soil

* Corresponding author.
E-mail address: Ashwell.Ndhlala@ul.ac.za (A.R. Ndhlala).

https://doi.org/10.1016/j.sajb.2025.05.005
0254-6299/

temperature, as reported in some environments (Turmel et al., 2015). In addition, organic mulch has been promoted with little success due to the trade-offs associated with the low amount of biomass (Nyambo et al., 2020b). Therefore, exploring alternative mulching techniques that can potentially boost soil and crop productivity is essential.

Plastic mulching has been extensively employed to enhance the productivity of horticultural crops, primarily focusing on fruits and vegetables while overlooking other high-nutritional and economically valuable horticultural crops. The main objective of utilizing-coloured plastic mulches is to modify the radiation budget and minimize soil water loss (Amare and Desta, 2021); the effectiveness of plastic mulches in mitigating the adverse effects of environmental stressors on crops is mainly dependent upon the color of the mulch. For instance, black plastic mulch has been shown to enhance the growth of blueberry plants (Strik et al., 2012a), while Shah et al. (2018) reported similar benefits for lettuce, and Karki et al. (2020b) found it effective for potatoes and cucumbers. In contrast, red plastic mulch has been associated with improved growth in red bell peppers and lettuce (Decoteau, 2008; Manganelli, 2017). However, black plastic mulch reduced the yield of thyme (Taylor et al., 2008), while silver plastic mulch yielded higher bell pepper production than black mulch (Díaz-Pérez, 2010). The observed increase in fruit yield in mulched plots is attributed to improved moisture retention and enhanced microclimatic conditions above and below the soil. These favourable conditions promote better plant growth and development, producing more fruit than unmulched plots. The beneficial effects of plastic mulches on the plant's microenvironment and root zone temperature facilitate cell expansion and growth. This study investigates how different mulching materials influence moringa growth, yield, and nutritional quality.

2. Material and methods

2.1. Description of the experimental site

The study was conducted at the University of Fort Hare Research Farm (32° 46′ 282″ S and 26° 50′ 067″ E, at an altitude of 508 m above sea level) (Fig. 1). The experimental site receives an average annual rainfall of 535 mm and has a mean annual temperature of 18.7 °C (Nyambo et al., 2020c).

2.2. Experimental design and treatment

The experiment investigated the effects of different mulching materials on growth, yield, and quality of moringa leaves. It was arranged in a randomized complete block design (RCBD) with four replications. The study compared three types of mulching treatments: (1) plant residues, (2) different colored plastic mulches, and (3) no mulch (control). The treatments included: (1) control (NM), (2) plant residues (OG), (3) red plastic mulch (PR), (4) black plastic mulch (PB), (5) green plastic mulch (PG), and (6) white plastic mulch (PW). All plastic mulches had a thickness of 50 μm. Seeds of moringa cultivar PKM1 obtained from world vegetable were directly sowed and grown (1.25 L) black polythene bags filled with hygromix growing media. Only those seedlings that reached 30 cm in height were transplanted into the experimental field, which was covered with the respective mulch treatments. During the seedling establishment stage, irrigation was applied every 7–10 days. After transplanting, the trees were irrigated three times per week using drip irrigation.

Each plant received 10 kg of farmyard manure as a basal application at sowing. Each plot consisted of three rows, with ten plants per

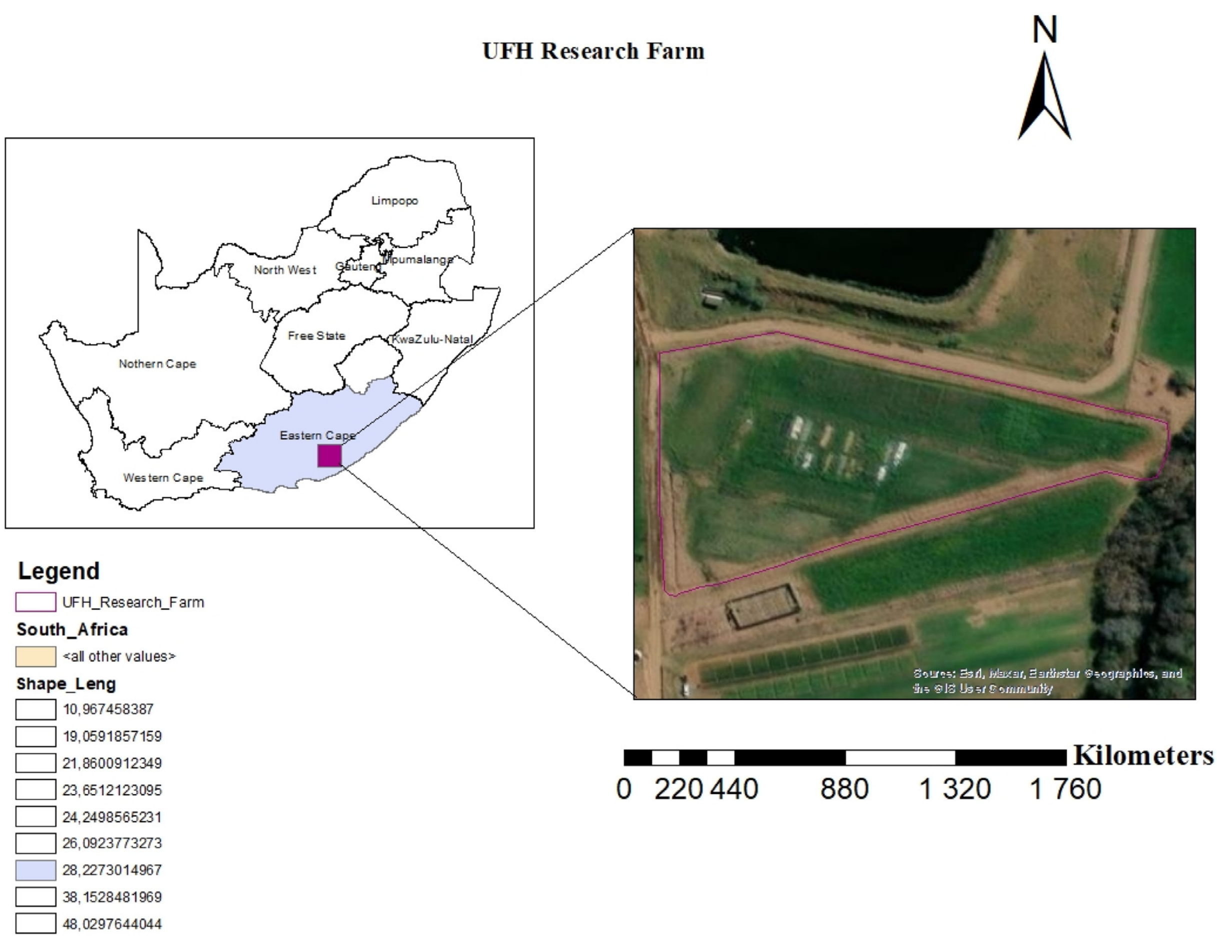

Fig. 1. Study area map of the University of Fort Hare research farm Eastern Cape Province.

row, resulting in thirty plants per plot. The field was designed with an inter-row spacing of 1 m and an intra-row spacing of 1.5 m, with each plot measuring 18 m in length. Pathways between plots were 1.5 m wide, and the distance between blocks was 1 m. Growth data was collected weekly from the middle row of each plot, commencing at 4 weeks after transplanting over the period of 8 weeks and was terminated flowering. In the plastic mulch treatments, cross slashes (approximately 5 cm) were made in the polyethylene sheets through which the seedlings were planted.

2.3. Measurements

Plant growth parameters such as root collar diameter was measured using a Vernier calliper, and plant height was measured using a meter ruler. Chlorophyll content was measured using a chlorophyll (SPAD) meter (Konica Minolta model SPAD-502), where three leaves per plant were measured and averaged for final chlorophyll content. Fresh biomass was determined by weighing the leaves soon after harvesting, while dry biomass yield was determined after weighing dried leaves.

Nutritional analysis was done on oven-dried leaves collected at the termination of the trial, the 13th week after transplanting. Moisture, ash, and fat contents were determined using the standard procedures of the Association of Official Analytical Chemistry (AOAC, 1990). Total nitrogen content was determined using the Kjeldahl method following Pearson (1976). A factor of 6.25 was used to convert the nitrogen content into crude protein. NDF and ADF were analysed using the methods described by Goering and Van Soest (1970). Micro- and macro-elements were determined after digesting the leaf samples using aqua regia (3:1 v/v hydrochloric acid (37 %): nitric acid (55 %)) in a MARS 5 microwave digester (CEM Corporation, Matthews, North Carolina).

2.4. Statistical analysis

Data collected were subjected to statistical analyses using JMP 15.0 statistical software (SAS Institute, Inc., Cary, NC, USA). Means were separated using Turkey's test at $p < 0.05$ when ANOVA indicated a significant P-value. Significant differences were identified at three probability levels; $p < 0.05$, 0.01 and 0.001. The study was done over twenty-two weeks; therefore, time was introduced as an extra factor when analyzing for growth. A two-way ANOVA was carried out to determine significant influence of mulching on growth, yield and nutritional quality of moringa.

Table 3.1
Analysis of variance (ANOVA) for plant height, stem diameter and chlorophyl index.

Source of variation	Plant height	Stem diameter	Chlorophyll
Mulch	***	***	***
Time	***	***	**
Mulch * Time	***	*	ns
CV	8.99	17.03	9.56

*, **, *** Significance at 0.05, 0.001 and 0.01 probability level, respectively; CV: coefficient of variance.

3. Results

3.1. Plant growth parameters

Application of mulching treatments showed significant differences, the significant differences were identified at three probability levels; $p < 0.05$, 0.01 and 0.001 in plant growth, yield, and chlorophyll index (Table 3.1).

An increasing trend of growth in relation to plant height was observed in black plastic mulch throughout the growing period (Fig. 2). The black plastic mulch resulted on a significant ($p < 0.005$) increase on plant height over time. For instance, the black plastic mulch at 6 and 13 weeks after transplanting (178 cm and 292 cm) resulted in the tallest trees compared to red, white plastic, organic mulch and control (unmulched). The shortest trees were observed in the unmulched plots at 6 and 13 weeks after transplanting (35 cm and 79 cm).

The plant stem diameter showed a similar trend (Fig. 3). The black plastic mulch resulted in thicker stem as growth progressed. For instance, black and red plastic mulch at 6 weeks were not significantly different from each other, although the black plastic mulch was different from green and white plastic and organic and unmulched plots. However, 13 weeks the black, red and green plastic mulch were significantly different from the white plastic, organic

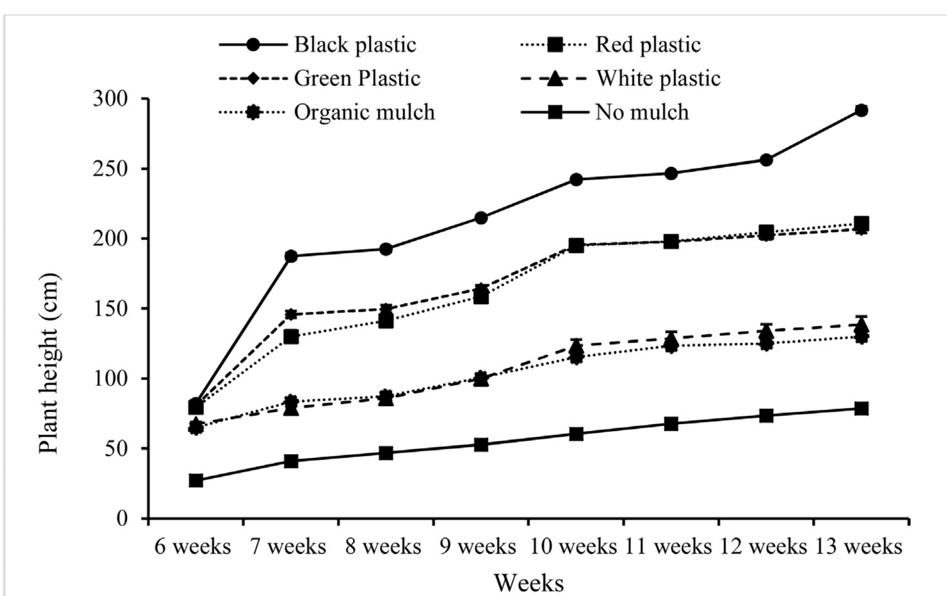

Fig. 2. The interaction effect of mulch over time on the plant height of moringa trees.

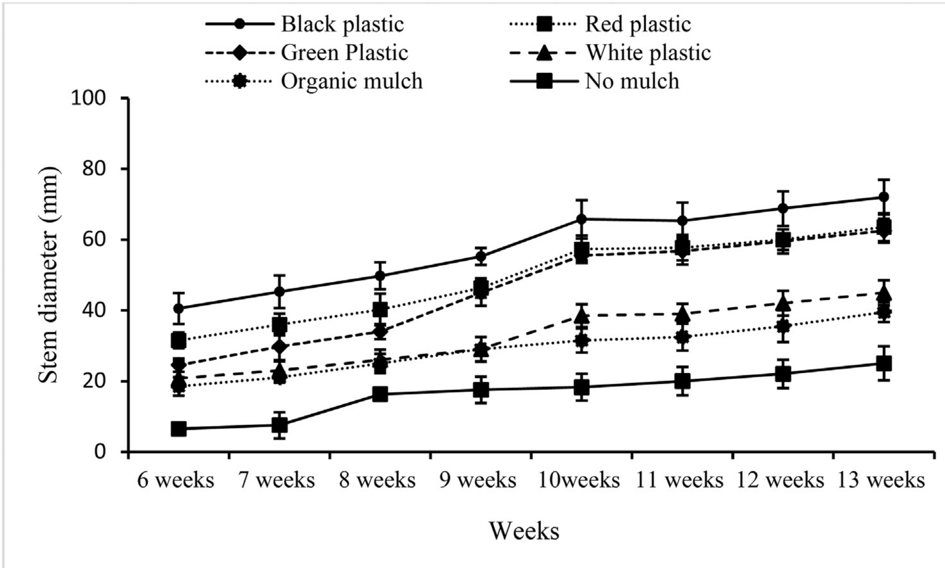

Fig. 3. The interaction effect of mulch and time on stem diameter of moringa trees.

mulch and control. The thickest stems at 6 and 13 weeks after transplanting (40 mm and 72 mm) and were observed in black plastic mulch while the thinnest stems were at 6 and 13 weeks after transplanting (6 mm and 25 mm) were observed in the unmulched plots.

The chlorophyll content of moringa leaves showed significant increase in black plastic mulch compared to other mulching material over the weeks (Fig. 4). The highest chlorophyll content (75) at 13 weeks after transplanting was observed in plant mulched with black plastic, while the lowest chlorophyll content (59.2) at 13 weeks after transplanting was observed in the control.

The fresh mass of the moringa leaves was significantly higher in black plastic mulch (13.16 kg/ha) than the other mulching materials and the lowest fresh mass was obtained in the control (3.45 kg/ha) (Table 3.2). After the plants were subjected to oven drying, the black plastic resulted in higher dry leaves content (1.84 kg/ha) while the control resulted in lower (0.43 kg/ha) dry leaves content. Overall, the black plastic mulch resulted in higher dry matter content (14 %) compared to other treatments and the lowest dry matter content was obtained from the control (12,4 %).

3.2. Proximate leaf nutrient analysis

The proximate and mineral composition of plants offers valuable insights into their medicinal and nutritional benefits (Khan et al., 2025). The analysis of variance detected some significant differences ($p < 0.05$) between the variables being tested as a response to different mulching methods. The results indicated that moringa leaves contained appreciable amounts of crude protein (CP), ash, fat, acid detergent fiber (ADF), neutral detergent fiber (NDF) and moisture content (Table 3.3). The highest moisture content of 8.29 % was obtained from Black plastic mulch while the lowest moisture content of 7.28 % was obtained from the control. The highest ash content of 14.93 % was obtained from black plastic mulch and the lowest ash content of 12.84 % was obtained from the control.

The fat content of black, white, and red plastic mulch was significantly different green, organic mulch, and control. The highest fat content of 4.92 % was observed in black plastic mulched plots while the lowest fat content of 3.95 % was observed in the control. The ADF content of moringa leaves obtained from plots that had black plastic

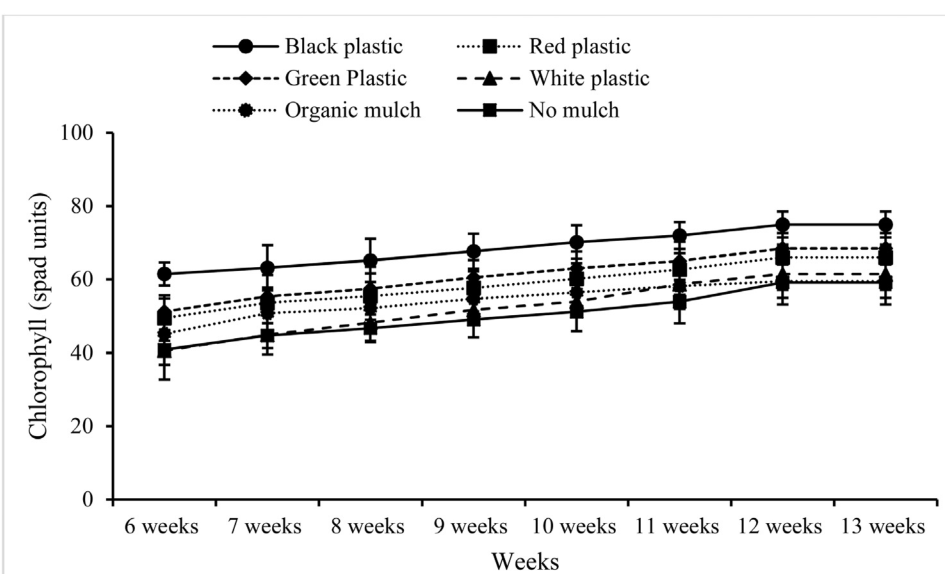

Fig. 4. The influence of plastic mulch on chlorophyll content of moringa leaves.

Table 3.2
Yield of Moringa as influenced by different mulching materials.

Treatment	Fresh mass (kg/ha)	Dry mass (kg/ha)	Dry matter content (%)
Plastic black	13.16a	1.84a	14.00a
Plastic green	7.72b	1.02b	13.20b
Plastic red	5.63c	0.71c	13.18b
Plastic white	4.66cd	0.57d	13.65b
Organic mulch	3.65d	0.48de	13.15b
No mulch	3.45d	0.43e	12.40c
Mulch	***	***	*
CV (%)	9.53	6.79	5.00
LSD ($p < 0.05$)	0.92	0.08	0.97

Figures in the same column with the same letters are not significantly different from one another. CV = coefficient of variance, LSD = least significant.

Tables 3.3
Proximate nutrient analysis of moringa leaves as influenced by different mulching materials.

Treatment	Moisture	Ash	Fat	ADF	NDF	Crude Protein
Plastic black	8.29a	14.93a	4.92a	29.87a	42.99a	27.93a
Plastic white	7.84abc	14.20ab	4.78a	27.68ab	40.21b	25.53b
Plastic red	7.85abc	13.95b	4.64ab	26.97ab	40.11b	25.99ab
Plastic green	7.95ab	13.99b	4.22bc	26.61ab	40.74ab	25.00bc
Organic mulch	7.47bc	13.62bc	4.17c	25.27bc	38.25bc	24.34bc
No mulch	7.28c	12.84c	3.95c	22.99c	36.14c	23.19c
Mulch	***	***	***	**	***	***
Grand mean	7.78	13.92	4.45	26.57	43.21	25.33
CV (%)	4.40	4.22	9.55	9.53	5.21	5.85
LSD ($P < 0.05$)	0.51	0.88	0.64	3.82	3.12	2.23

Figures in the same column with the same letters are not significantly different from one another. CV = coefficient of variance, LSD = least significant.

mulch was significantly different from organic mulch and control. The highest ADF content of 29.87 % was obtained from the black plastic mulch whereas the lowest content of 22.99 % was obtained from the control. The NDF of black plastic mulched plots content differed significantly from the white, red, organic mulch and control. Also, the white, red, and green plastic mulch differed significantly from the control. Resulting to highest NDF (42.99 %) discovered in black plastic mulched plots and lowest content (36.14 %) obtained from the control.

The crude protein of black plastic mulch was notably significantly different from white, green, organic material, and control plots. Moreover, the white and red plastic mulch differed significantly from the control. The highest crude protein (27.93 %) was obtained from black plastic mulched plots. In addition, the lowest crude protein (23.19 %) was observed from the control. The increased proximate nutritional contents obtained from the study indicate that moringa is a reliable source of essential nutrients required for the supplementation of feed for livestock and improve diets for human consumption.

3.2.1. *Macro nutrient*

The analysis of variance showed that macro-minerals were significantly affected by the different mulching materials. The phosphorus content in (Fig. 5a) in plots mulched with black plastic was significantly different than the rest of the treatments. The phosphorus content in plots with black plastic mulch was notably 80 % higher compared to the rest of the treatments. The plots with no mulch had 49 % lower phosphorus content. The nitrogen content (Fig. 5b) in black plastic significantly increased and differed significantly from the control, even though the black plastic was not significantly different from other treatments used. Moreover, the highest concentration of nitrogen (3.8 %) was observed in black plastic while the lower concentration of nitrogen (3.4 %) was observed control.

Calcium content (Fig. 5c) of the leaves in the current trail ranged between 2.73 % and 3.32 %. Apparently, the plants grown in black plastic mulch had the highest Ca content of 3.32 % and were significantly different from the plants grown in control. The plants grown in control had the lowest Ca content of about 2.73 %. The black plastic mulch was not significantly different from red plastic mulch. However, it differed significantly from the green, white plastics, organic

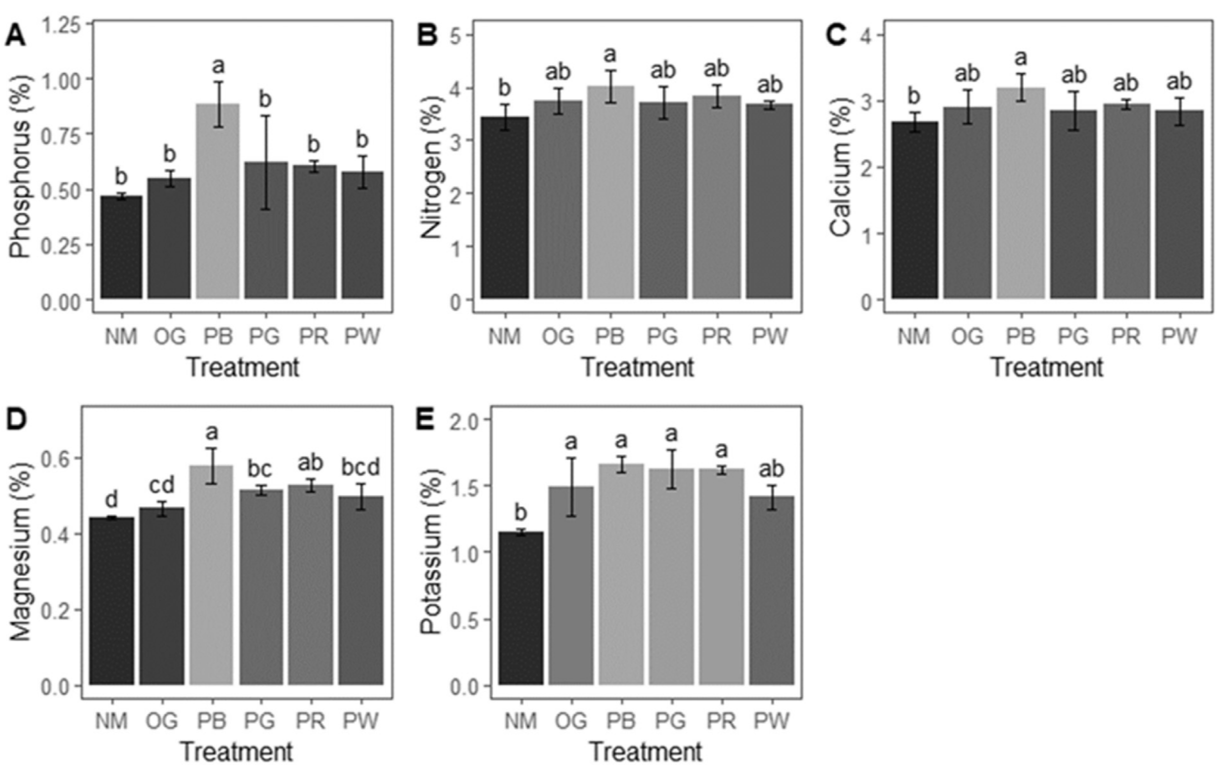

Fig. 5. Macronutrient content of moringa leaves grown under different mulching materials. Bars that share the same letters are not significantly different from one another. Error bars represent standard error. NM- no mulch; OG- organic mulch; PB- black plastic; PR- red plastic and PW- white plastic.

and the control. The highest Magnesium (Fig. 5d) content of approximately 59 % was observed in black plastic mulch. However, the lowest magnesium content of about 45 % was observed in the control. The results of the analysis of variance indicated that organic mulch, green, and black plastic mulch were significantly different from the control (Fig. 5e).

The highest concentration of K (1.8 %) was obtained in black plastic mulch, and the lowest concentration of K (1.3 %) was observed in the control.

3.2.2. Micro-nutrients

The results of the study revealed that the analysis of variance showed that the determined micro-minerals were significantly affected by different mulching materials. In Fig. 6a, the illustration shows that the application of different mulching material significantly influences the concentration of Na in moringa plants. The black plastic mulch and red plastic mulch treatment resulted in a significantly high Na concentration in moringa leaves. The highest Na concentration of 1387 mg/kg was observed from the red plastic mulch and the lowest Na concentration of 672 mg/kg was observed from the control. The manganese content (Fig. 6c) in black plastic mulch and red plastic mulch were significantly different from green, white, organic mulch and control. The highest Mn content of 149 mg/kg was observed in black plastic mulch and the lowest Mn content of 97 mg/kg was observed in the control.

The Iron content (Fig. 6d) in black plastic mulch was significantly different from white, green plastic mulch, organic mulch, and the control. The highest Fe content of approximately 125 mg/kg was noted from plants mulched with black plastic, whereas the lowest Fe content of approximately 95 mg/kg was observed from plants grown in the control. The Aluminium content (Fig. 6e), in black plastic and red plastic mulch were significantly different from plants grown in green, white plastic mulch. The white and red plastic mulch were significantly different from organic mulch and the control. Nonetheless, the highest Al content of approximately 71.25 mg/kg was noted in black plastic, whereas the lowest Al content of approximately 49.35 mg/kg was observed in the control. The zinc content (Fig. 6f) indicated that the plots mulched with plastics were significantly different from the organic mulch and the control. However, comparison within plastics indicated that the black plastic differed significantly from the green and white plastic mulch. The highest Zn content of approximately 22.45 mg/kg was noted from plants mulched with black plastic, whereas the lowest Zn content of approximately 15.35 mg/kg was observed from plants grown in the control.

4. Discussion

4.1. Plant growth parameters

Mulching provides an optimal growth environment by providing adequate moisture and regulating root zone temperature, which enhances plant growth and development. The application of different mulching materials improves the microclimate around plants leading to increased cell expansion and elongation enhancing plant growth and development (Li et al., 2004). The effectiveness of plastic mulches in mitigating environmental stress on crops is significantly influenced by the color of the mulch (Amare and Desta, 2021). The mean soil temperature affects plant growth characteristics such as stem diameter, plant height, leaf length, leaf dry weight, stem dry weight, and plant dry weight (Gheshm and Brown, 2020). According to Shah et al. (2018), the black polyethylene resulted in an increased number of leaves, longleaf, and wider leaf breadth in lettuce, followed by white, blue, silver, and olive film. On the contrary, Mendonça et al. (2021) reported that plants grown in red plastic mulch showed high performance in comparison to plants grown in black plastic mulch. However, this was not the case for the current study. High crop performance was observed in plants grown in black plastic mulch.

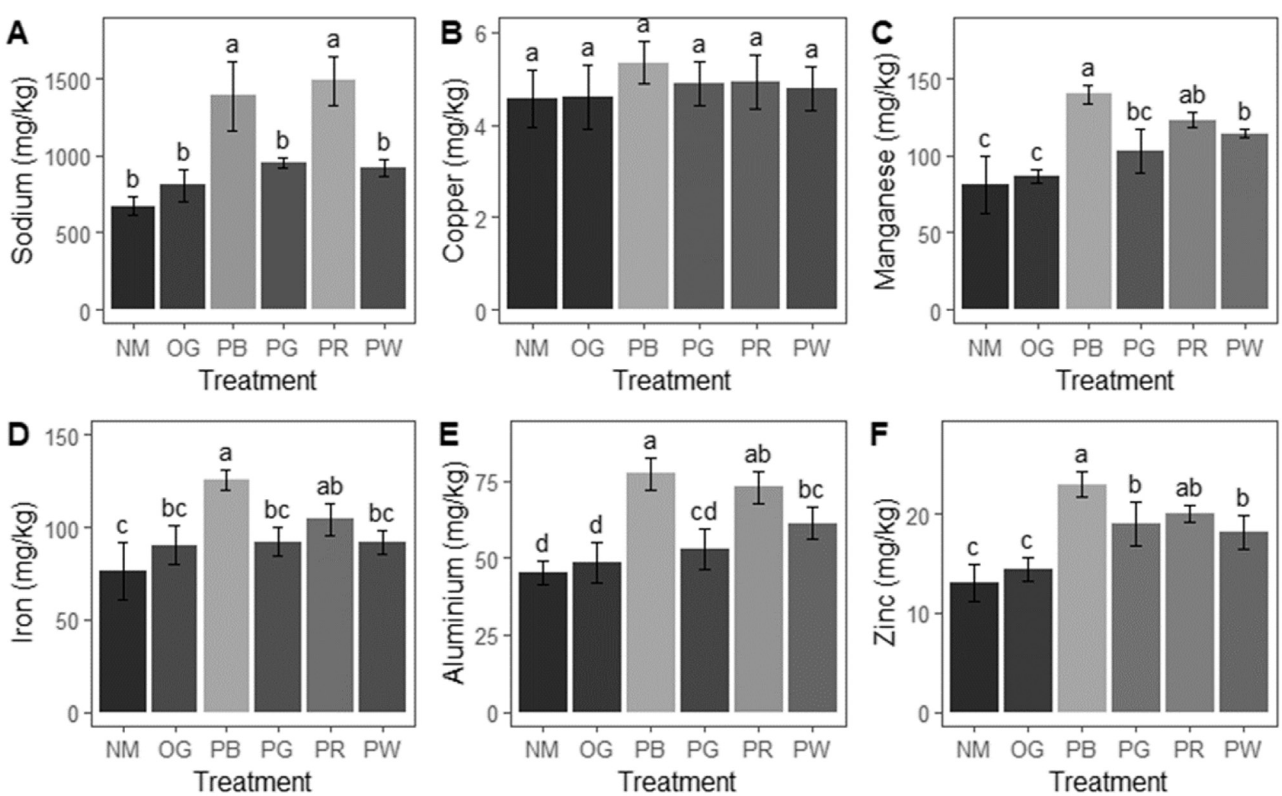

Fig. 6. Micronutrient content of moringa leaves grown under different mulching materials. Bars that share the same letters are not significantly different from one another. Error bars represent standard error. NM- no mulch; OG- organic mulch; PB- black plastic; PR- red plastic and PW- white plastic.

The use of plastic mulch significantly improves growth attributes, which might be due to the enhancement of photosynthesis and other metabolic activities (Bhatt et al., 2011; Parmar et al., 2013). The chlorophyll content is a key indicator of a plant's photosynthetic efficiency. According to Zhang et al. (2022), higher SPAD values reflect better chlorophyll content and enhanced photosynthetic capability. In the current study, plants grown under black plastic mulch exhibited significantly higher chlorophyll content, suggesting improved photosynthetic performance and potentially better yields. These findings agree with Fu et al. (2022), which reported that maize grown in black plastic mulch had higher chlorophyll content compared to those grown in white plastic mulch and unmulched plots. Subsequently, Jahan et al. (2018), reported that lettuce mulched in black plastic resulted in increased chlorophyll than unmulched plots. The improved growing conditions enhance the plant growth and development and produced an increased fruit-bearing environment compared to no mulched plots.

The improved growing conditions enhanced the plant growth and development and produced an increased fruit-bearing environment compared to no mulched plots. Also, covering the soil has an effect on the lack of evaporation from the surface of the soil, which reduces the rise of water to the top by capillary action and thus prevents the accumulation of salt in the root area of the plant and the increase in the moisture stock of the root zone due to coverage. It may cause a decrease in the salt concentration in the surface layer of the soil and thus allow growth, division and elongation of cells and in turn positively reflects on improving the traits of vegetative growth and affecting the increase in yield traits. Plastic mulching has the potential to improve soil temperature, reduce evaporation from soil, increase dioxide concentration and nutrients, control weeds, protect plants from pests and reduce fruit rotting.

4.2. Proximate nutrient analysis

Moringa is an indigenous source of highly digestible proteins, calcium, iron, and vitamin C. The presence of these essential nutrients and minerals implies that moringa leaves could be utilized as a nutritionally valuable and healthy ingredient for both animal and human consumption. While these nutrients may not be solely medicinal, they could play a significant role in preventing malnutrition. The moisture content of 8.29 % obtained in black plastic mulched plots falls within range of the standard moisture content recommendation by (Fahey, 2005). However, Osadebe et al. (2014) reported no significant difference in the values of the moisture content of the fluted pumpkin when subjected to different mulching materials. Okwu and Morah (2004) reported that high moisture content in vegetables is a quality attribute that indicates the extent of freshness in the vegetables. The high level of moisture content in leaves results in the growth of moulds; therefore, the level of moisture content obtained in the current study, indicates that moringa leaves are protected from enzymatic decomposition.

The proximate nutrient analysis showed that moringa leaves contain significant amounts of crude protein, ranging from 23.19 % to 27.93 %. The protein content in this study aligns with the range of 23.94 % to 42.12 % reported by Osadebe et al. (2014) for fluted pumpkin grown in black plastic mulched plots. In contrast, Nursandi et al. (2017) reported a much lower crude protein content of 13.60 % to 14.43 % in plots mulched with wood shavings. Similarly, Sule et al. (2014) reported that maize grain in Nigeria had a lower protein content, ranging from 10.67 % to 11.25 %. The differences in protein accumulation can be explained by Rafiq et al. (2010), who found that mulches help retain soil moisture and enhance fertility, leading to increased protein content in crops. Additionally, Boomsma et al. (2009) indicated that plants with sufficient moisture and nitrogen in the soil can produce more chlorophyll and engage in higher rates of photosynthesis, ultimately resulting in crops with increased protein levels.

The ash content of 14.93 % of the study obtained from black plastic mulch is relatively higher than 13 % ash content reported by Osadebe et al. (2014) obtained from black polyethylene mulch and 8 % of *Hibiscus esculentus* reported by (Akindahunsi and Salawu, 2005). However, Dairo and Adanlawo (2007), reported higher ash range of 16,30 % to 17,31 %, which was significantly higher than the ash content obtained from the study. Contrary, Adebimpe et al. (2024) reported that lower ash content of 5.45 % stem to leaves of *E. purpurea* obtained from black plastic mulching materials. The variation between the ash content may be attributed to different mulching materials used. In addition, Adebimpe et al. (2024) agrees that the variation observed in protein and ash content could be explained by many factors, involving the environment, abiotic stress, the genetic heritance maturity of the plants and the type of mulching material applied during the cultivation of the plants. Therefore, the ash content observed in the current results, regardless of treatment, indicates that dried leaves of moringa are a reliable source of mineral element.

The ADF and NDF content accumulation was notably higher in plastic mulched plots in comparison with organic mulched plots and the control. There is scarcity of literature that has reported the influence of plastic mulch on NDF and ADF content. Therefore, the increased values of ADF and NDF content in moringa could be attributed to high temperatures and dry conditions in the summer season of the Eastern Cape Province. Extremely high temperature and moisture stress reduce forage quality by lowering leaf/stem ratio, intensifying lignification, and increasing ADF and NDF contents (Kering et al., 2011). Mulching results to modified microclimatic conditions around the root zone of the plants, the black plastic traps more sun rays which results to increased heat around the root zone and therefore increases the production of ADF and NDF by plants ADF and NDF contents in black plastic mulched plots. The increased soil temperature associated with mulching may be linked to elevated levels of nitrogen, phosphorus, and potassium found in the leaves (Ghazal and Al-Nussairaw, 2022).

These nutrient enhancements can improve root growth and the plant's ability to absorb water and nutrients from the soil. Consequently, this is reflected in enhanced root and vegetative development, which stimulates the growth of plant tips and promotes the synthesis of growth hormones such as gibberellins and auxins (Ghazal and Al-Nussairaw, 2022). The accumulation of nutrients in the leaves supports vegetative growth characteristics, ultimately leading to improved yield. The plastic mulch contributes to nutrient retention within the root zone, thus, promoting efficient nutrient use by the vegetable crop.

5. Conclusion

The use of different colored plastic mulches, particularly the black plastic mulch, has significantly improved the growth, yield and nutritional quality of moringa through its unique light-modifying properties. The improved growth, yield and nutritional quality in plants mulched with black plastic could be associated the ability of black colour to absorb light to alter the soil microclimate and playing a crucial role in regulating soil temperature, suppressing weeds, and conserving soil moisture.

Moringa is a rich source of highly digestible proteins, calcium, iron, and vitamin C. Due to their rich nutrient profile, moringa leaves are considered a valuable source of food for both animals and humans, with the potential to alleviate malnutrition-related health issues. Given the importance of moisture retention, nutrient availability, and fibre composition in determining the nutritional quality of moringa, our results affirm that integrating plastic mulches into moringa cultivation can optimize growth conditions and enhance productivity. Studies exploring the interactions between plastic mulching and other sustainable agricultural practices could further enhance the role of moringa in promoting food security and supporting resilient agricultural systems.

Conflict statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

CRediT authorship contribution statement

Asanda Sokombela: Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ashwell R. Ndhlala:** Writing – review & editing, Validation, Supervision, Software, Resources, Project administration, Funding acquisition, Conceptualization. **Moshibudi P. Bopape-Mabapa:** Writing – review & editing, Visualization, Supervision, Resources, Project administration, Conceptualization. **Bahlebi K. Eiasu:** Writing – review & editing, Visualization, Validation, Supervision, Software, Methodology, Formal analysis, Data curation, Conceptualization.

Funding

This work was supported by the Department of Science and Innovation South African Government [grant numbers DSCI/CONC2235/2021].

Acknowledgements

The authors are grateful to the Department of Science and Innovation for funding the research.

References

Adebimpe Ojo, C., Dziadek, K., Sadowska, U., Skoczylas, J., Kopeć, A., 2024. Analytical assessment of the antioxidant properties of the coneflower (Echinacea purpurea L. Moench) grown with various mulch materials. Molecules 29 (5), 971.

Akindahunsi, A.A., Salawu, S.O., 2005. Phytochemical screening and nutrient/antinutrient composition of selected tropical green leafy vegetables. Afr. J. Biotechnol. (4), 497–501.

Amare, G., Desta, B., 2021. Colored plastic mulches: impact on soil properties and crop productivity. Chem. Biol. Technol. Agric. 8 (1), 1–9.

Association of Official Analytical Chemistry [AOAC], 1990. In: Helrich, K. (Ed.), Official Methods of Analysis. 15th ed. Association of Official Analytical Chemists, Inc, Arlington, VA, USA.

Bhatt, L., Rana, R., Uniyal, S.P., Singh, V.P., 2011. Effect of mulch materials on vegetative characters, yield and economics of summer squash (*Cucurbita pepo*) under rainfed mid-hill condition of Uttarakhand. Veg. Sci. 38, 165–168.

Boomsma, C.R., Santini, J.B., Tollenaar, M., Vyn, T.J., 2009. Maize morphophysiological response analysis and review. Agron. J. 101, 1426–1452.

Chen, G., Sun, W., Wang, X., Kongkiatpaiboon, S., Cai, X., 2019. Conserving threatened widespread species: a case study using a traditional medicinal plant in Asia. Biodivers. Conserv. 28, 213–227.

Dairo, F.A., Adanlawo, I.G., 2007. Nutritional quality of Crassocephalum crepidioides and Senecio biafrae. Pak. J. Nutr. 6, 35–39.

Daryanto, S., Fu, B., Wang, L., Jacinthe, P.A., Zhao, W., 2018. Quantitative synthesis on the ecosystem services of cover crops. Earth-Sci. Rev. 185, 357–373.

Decoteau, D.R., 2008. The emergence and early development of colored reflective plastic mulch technology in agriculture. En: Stevens, C.; Khan, V.A. Recent Advances in Agriculture. Res Signpost Kerala, India, p. 1–17, 2008.

Díaz-Pérez, J.C., 2010. Bell pepper (*Capsicum annum* L) grown on plastic film mulches: effects on crop microenvironment, physiological attributes, and fruit yield. Horticult. Sci. 45, 1196–1204.

Fahey, J.W., 2005. *Moringa oleifera*: review of medical evidence for its nutritional, therapeutic, and prophylactic properties. Trees Life J. 1, 5.

Fu, Y., Si, L., Jin, Y., Xia, Z., Wang, Q., Lu, H., 2022. Efficacy of black plastic film mulching as a cultivation strategy to cope with leaf senescence and increase yield of rainfed spring maize (Zea mays L.). Soil Use Manage. 38 (1), 1044–1053.

Gadzirayi, C.T., Mudyiwa, S.M., Mupangwa, J.F., Gotosa, J., 2013. Cultivation practices and utilization of *Moringa oleifera* provenances by smallholder farmers: case of Zimbabwe. Asian J. Agric. Extens. Econ. Sociol. 152–162.

Ghazal, A.H., Al-Nussairaw, A.G.S., 2022. Effect of mulching, foliar application of amino acid on the growth and yield of cauliflower, *brassica oleracea var botrytis* L. Euphrates J. Agric. Sci. 14.

Gheshm, R., Brown, R.N., 2020. The effects of black and white plastic mulch on soil temperature and yield of crisphead lettuce in Southern New England. HortTechnology 30 (6), 781–788.

Goering, H.K., Van Soest, P.J., 1970. Forage Fiber Analysis. Agricultural Handbook No. 379. US Department of Agriculture, Washington, DC, pp. 1–20.

Groner, V.P., Nicholas, O., Mabhaudhi, T., Slotow, R., Akçakaya, H.R., Mace, G.M., Pearson, R.G., 2022. Climate change, land cover change, and overharvesting threaten a widely used medicinal plant in South Africa. Ecol. Appl. 32 (4), e2545.

Hopping, K.A., Chignell, S.M., Lambin, S.M., 2018. The demise of caterpillar fungus in the Himalayan region due to climate change and overharvesting. Proc. Natl. Acad. Sci. 115 (45), 11489–11494.

Jahan, M.S., Sarkar, D.M., Chakraborty, R., Solaiman, A.H.M., Akter, A., Sheng, S.H.U., Shirong, G.U.O., 2018. Impacts of plastic filming on growth environment, yield parameters and quality attributes of lettuce. Not. Sci. Biol. 10 (4), 522–529.

Karki, A., Sapkota, B., Bist, P., Bista, K., Dutta, J.P., Marahatta, S., Shrestha, B., 2020. Research article mulching materials affects growth and yield characters of cucumber. Afu. Edu. Np 4 (May 2018), 153–160.

Kering, M.K., Guretzky, J., Funderburg, E., Mosali, J., 2011. Effect of nitrogen fertilizer rate and harvest season on forage yield, quality, and macronutrient concentrations in midland Bermuda grass. Comm. Soil Sci. Plant Anal. 42 (16), 1958–1971. https://doi.org/10.1080/00103624.2011.591470.

Khan, M.N., Ullah, B., Kaplan, A., Wahab, S., Ali, B., Al Obaid, S., Ansari, M.J., 2025. An in-depth investigation of the nutraceutical value and medicinal perspectives of wild medicinal plants in Ojhor Valley, Hindukush Range, Chitral, Pakistan. Genet. Resour. Crop Evol. 72 (1), 557–585.

Lee, N., Thierfelder, C., 2017. Weed control under conservation agriculture in dryland smallholder farming systems of southern Africa. A review. Agron. Sustain. Develop. 37, 48.

Li, F.M., Wang, J., Xu, J.Z., Xu, H.L., 2004. Productivity and soil response to plastic film mulching durations for spring wheat on entisols in the semiarid Loess Plateau of China. Soil Till. Res. 78, 9–20.

Manganelli, C.C., 2017. Coloured plastic mulches improve the growth and yield of the 'Micro-Tom' tomato in high-density plantings

Mendonça, S.R., Ávila, M.C.R., Vital, R.G., Evangelista, Z.R., de Carvalho Pontes, N., dos Reis Nascimento, A., 2021. The effect of different mulching on tomato development and yield. Sci. Hortic. 275, 109657.

Moyo, B., Masika, P.J., Hugo, A., Muchenje, V., 2011. Nutritional characterization of moringa (Moringa oleifera Lam.) leaves. Afr. J. Biotechnol. 10 (60), 12925–12933.

Nursandi, F., Machmudi, M., Santoso, U., Indratmi, D., 2017. Properties of different aged jicama (Pachyrhizus Erozus) plants. IOP Conference Series: Earth and Environmental Science. 77, IOP Publishing, 012003.

Nyambo, P., Chiduza, C., Araya, T., 2020a. Carbon input and maize productivity as influenced by tillage, crop rotation, residue management and biochar in a semi-arid region in South Africa. Agronomy 10 (5), 705.

Nyambo, P., Chiduza, C., Araya, T., 2020b. Carbon dioxide fluxes and carbon stocks under conservation agricultural practices in South Africa. Agriculture 10 (9), 374.

Nyambo, P., Chiduza, C., Araya, T., 2020c. Carbon dioxide fluxes and carbon stocks under conservation agricultural practices in South Africa. Agriculture 10 (9), 374. https://doi.org/10.3390/agriculture10090374 2020.

Okwu, D.E., Morah, F.N.I., 2004. Mineral and nutritive value of *Dennettia tripetala* fruits. Fruits 59, 437–442.

Osadebe, V.O., Echezona, B.C., Bakare, S.O., 2014. Effect of weed management and cutting frequency on the leaf yield and proximate composition of fluted pumpkin (Telfairia occidentalis Hook F.). Am. Eur. J. Agric. Environ. Sci. 14 (7), 664–673.

Parmar, H.N., Polara, N.D., Viradiya, R.R., 2013. Effect of mulching material on growth, yield, and quality of watermelon (*Citrullus lanatus* thunb) cv. Kiran. Univ. J. Agric. Res. 1, 30–37. https://doi.org/10.13189/ujar.2013.010203.

Pearson, D., 1976. The Chemical Analysis of Foods, 7th Ed. Churchill Livingstone, London, pp. 3–4.

Rafiq, M.A., Ali, A., Malik, M.A., Hussain, M., 2010. Effects of mulches and plant densities on yield and protein contents of autumn planted maize. Pak. J. Agric. Sci. 47 (3), 201–208.

Raman, J.K., Alves, C.M., Gnansounou, E., 2018. A review on Moringa tree and vetiver grass–potential biorefinery feedstocks. Bioresour. Technol. 249, 1044–1051.

Shah, J.M., Sarkar, D.M., Chakraborty, R., Muhammad Solaiman, A.H., Akter, A., Shu, S., Guo, S., 2018. Impacts of plastic filming on the growth environment, yield parameters, and quality attributes of lettuce. Not. Sci. Biol. 10, 522–529.

Singh, N., Dwivedi, D.H., Kishor, S., Maji, S., 2021. Improvement in growth and yield of strawberry (*Fragaria× ananassa Duch.*) in a mulch colour. Environ. Sustain. 1–6.

Sokombela, A., Eiasu, B.K., Nyambo, P., 2022. Nitrogen and phosphorus fertilizers improve growth and leaf nutrient composition of moringa oleifera. Front. Sustain. Food Syst. 6, 861400.

Strik, B., Bryla, D., Larco, H., Julian, J., 2012. The economics of establishing blueberries for organic production in Oregon—a comparison of weed management systems. Acta Hortic. 810, 457–464.

Sule, E.I., Umoh, V.J., Whomg, C.M.Z., Abdullahi, I.O., Alabi, O., 2014. Chemical and nutritional value of maize and maize products obtained from selected markets in Kaduna state, Nigeria. Afr. J. Food Sci. Technol. 5 (4), 100–104.

Taylor, P., Aziz, N., Sauve, R.J., Long, D., Cherry, M., 2008. Genetic and phytochemical diversity assessment among eleven hypericum accessions via AFLP and HPLC Analyses Genetic and phytochemical diversity assessment among eleven Hypericum accessions via AFLP and HPLC analyses. J. Herbs Spices Med. Plants 2, 37–41.

Turmel, M.S., Speratti, A., Baudron, F., Verhulst, N., Govaerts, B., 2015. Crop residue management and soil health: a systems analysis. Agric. Syst. 134, 6–16.

Zhang, R., Yang, P., Liu, S., Wang, C., Liu, J., 2022. Evaluation of the methods for estimating leaf chlorophyll content with SPAD chlorophyll meters. Remote Sens. 14 (20), 5144.