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Research Article

Effect of biomass ash vermicompost on *Sorghum bicolor* var. *saccharatum* (L.) Mohlenbr under hot and dry agro ecological condition

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ABSTRACT

Generation of the huge amount of bio-waste and their residues, including incineration ash, is a major technical and sustainability problem. To solve this problem, incorporating nutrient-rich residues into crop production has become an efficient practice to increase crop production. Vermicomposting of these wastes could be a viable option to manage both bio-wastes and their products in an environmentally friendly manner and close the material loop in bioenergy production. Therefore, the main objective of this study was to investigate the effect of vermicompost from biomass ash under hot and dry climatic conditions in summer on growth, yield and yield components of sweet sorghum (*Sorghum bicolor var. saccharatum* (L.) Mohlenbr). The high photosynthetic activity of sweet sorghum is important for biofuel production under conditions of high solar energy and water scarcity. This study provides a general overview of the feasibility of biomass ash vermicomposting processes and their potential use as a nutrient source for C4 sorghum under Bitlis ecological conditions of high solar potential and low water availability. Under Bitlis climatic conditions, the best yield was obtained when vermicompost was applied with a biomass ash content of 10.0% (T3). Plant height, plant weight, sugarcane and juice yields were reported as 133 cm, 146 g, 180 kg/da and 105 L/da, respectively.

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INTRODUCTION

The increasing demand for energy from renewable resources has led to the expansion of biomass power plants, which results in the generation of biomass ash as an end product that must be properly disposed of according to the principles of circular economy [1]. Therefore, it is critical to find new methods to recycle nutrient-rich biomass ash in a closed-loop system of crop production and energy generation to reduce waste accumulation, increase crop productivity, and reduce environmental impacts [2]. Since biomass and biofuel production generate large amounts of residues, the approach of converting them into biofertilizers to produce new fuels can overcome the net-zero CO_2 goal for developing a sustainable energy source [3]. In addition, the trend of global warming combined with chang-

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ing rainfall regimes and high evapotranspiration for many cropping practices is destined to adapt more drought tolerant crops that are more efficient in managing nutrients and irrigation water under deficient environmental conditions [4]. A variety of waste-based, nutrient-rich organic fertilizers are being developed for recycling purposes and for fertilizing crops. Among them, vermicompost appears to be the most promising cost-effective method to convert recalcitrant biomass ash into valuable organic fertilizer for reuse in the production of biofuel feed stocks in closed-loop energy systems. Additionally, composting of organic waste stream offer the best disposal option especially in mineral resource use for crop production [5]. For instance, incorporating organic matter into the soil increases soil organic matter [6], increases the soil nutrient pool [7], minimizes soil nutrient depletion [8], acts as a slow-release fertilizer [9], improves porosity and infiltration [10], microbiological and enzymatic activity [11], and thus also improves water use efficiency of plants [12].

Among biofuels, bioethanol gains great popularity due to its numerous advantages. The sorghum plant offers a particularly high yield of biofuel under hot and dry climatic conditions [13]. The C4 sorghum plant (*Sorghum bicolor* var. *saccharatum* (L.) Mohlenbr) is characterized by high photosynthetic efficiency and high dry matter accumulation rate compared to other crops, especially under drought stress conditions. Due to its high biomass and sugar yield, it is more popular in hot and dry climates because it can withstand drought, requires lower water, fewer cultivation inputs, is easy to cultivate, and has lower fuel costs such as sugar syrup, bagasse, and grain yields. The potential to produce solid, liquid, and gaseous biofuels under conditions of high solar radiation and water deficit makes sorghum a unique, valuable crop for future challenging environmental conditions. Therefore, sweet sorghum appears to be the most promising energy crop in the hot and drought-prone regions where conventional crops with high water requirements such as corn, sugar beets, and sunflowers cannot be grown. Although sugar content in the plant stem is one of its most important characteristics, it also produces grains with high starch content and bagasse with high lignocellulose content [14], which can be fermented to produce bioethanol or solid biofuel.

Sweet sorghum is a high biomass and sugar yielding plant belonging to the C4 photosynthetic pathway. It produces plant stems up to 300 cm tall with a sugar content of 16–23% Brix, depending on the variety and agricultural inputs used. Unlike other C4 plants, it tolerates dry conditions, requires less fertilizer, and is easy and inexpensive to grow. When integrated into the cropping system, the application of vermicompost can further improve Brix content, sugar and biomass yield under high PAR (photosynthetic active radiation) and dry environmental conditions [15]. The particular advantage of sweet sorghum is its lower nitrogen requirement due to its high nitrogen use efficiency under water deficit conditions. However, yields can be increased by applying a balanced nutrient in the form of vermicompost, which copes very well with dry and hot climatic conditions due to its stress-reducing properties. It is reported that the dry biomass of sweet sorghum, grown as an alternative crop for biogas production in drought-prone areas, is 27% higher than that of maize under the experimental conditions of severe drought, which is due to the inherently deep and strong root exploitationin the subsoil [16]. On the other hand, a strong response to fertilizers is also reported. For example, in studying the effects of nitrogen and potassium fertilizers on growth parameters, it was found that an application of 180 kg urea per hectare at physiological maturity increased stem height by 12.65%, stem fresh weight by 24.57%, total weight by 78.22%, and total sugar content by 39.25%. When 50 kg of potassium sulfate was applied, the rates of increase were as follows: 24.33% in fresh stem weight, 25.44% in total weight, and 10.50% in total sugar content [17]. It is also reported that the optimum N fertilization is 59–110 kg N ha^{-1} and 200 kg N ha^{-1} for ethanol and sugar yield, respectively, which in contrast indicates lower sugar quality and ethanol yield [18].

In recent years, the focus has shifted to the use of feed stocks for biofuels, as food crops can only meet a small portion of the demand for biofuels and require intensive fertilization [19]. The main problem in biofuel production is the cost of the feed stock. As an alternative to the high demanding biofuel crops, sweet sorghum can serve as a sustainable biofuel feedstock that requires few inputs, is tolerant of environmental changes, and offers versatile processing options. As an alternative to chemical fertilizers, biofuel yields can be enhanced by sustainable nutrient resources such as vermicompost, whose nutrient content is enriched by biomass ash produced at biomass power plants. Biomass ash contains high levels of most fertilizer nutrients such as phosphorus and potassium. However, due to its high pH for agricultural use, it remains in the background in agricultural applications. Although various methods are used to recover the phosphorus contained in biomass ash in the form of apatite, the application of vermicompost can be sustainable and provide an environmentally friendly recovery [20]. Although several studies have highlighted the response of some crops to vermicompost nutrients [21] the role of biomass ash vermicompost in improving biofuel yield of sweet sorghum in hot, dry agroecosystems has not been thoroughly investigated. The results of this work could show the effects of nutrient-rich biomass ash vermicompost on biomass yield and feedstock composition of sweet sorghum in Bitlis, Turkey, which has hot summer climatic conditions with high sunshine hours.

MATERIALS AND METHODS

Vermicompost Preparation

Biomass ash is a rich source of nonvolatile plant macro- and micronutrients. Similarly, dairy manure consists of volatile nutrients abundant in nitrogen, carbon, and sulfur, which play essential roles in plant nutrition and sugar metabolism. To test the first hypothesis, the possibility of enriching vermicompost with both volatile nutrients from biowaste and non-volatile nutrients from biomass ash was examined. Therefore, vermicompost was made from a combination of dairy manure and biomass power plant ash to produce a slow-release organic biofertilizer. The biomass ash (BA) was obtained from a biomass power plant in Sakarya, Turkey. BA came from sawdust, forest residues, nut shells, and mainly poultry litter. The Turkish compost regulation specifies that the total value for N (Nitrogen), P (Phosphorus) and K (Potassium) in worm compost must not exceed 7.0%. Considering this limit, the final NPK content in vermicompost samples was 0.0% (T0 without BA), 3.5% (T1), 7.0% (T2), and 10.0% (T3), respectively [20]. The process of vermicomposting involves two phases. The first phase is performed by aerobic microbes that reduce the readily biodegradable substrate to minimize the negative effects of toxic and odorous compounds on worms. The second phase is performed by worms and gut microbes to obtain a more humified product that helps plants mobilize and absorb nutrients, but also promotes plant growth and inhibits plant pests. After homogeneously incorporating the calculated amount of BA into the dewatered cattle manure, the mixture was allowed to ferment for 21 days to prevent negative effects of volatiles and toxic substances on the vermicompost process. The vermicompost-forming materials were then incubated at room temperature and under humid conditions by spraying the surface with water in a dark environment. Processing was carried out for 60 days to allow the compost to mature [22].

Plant

The sweet sorghum plant is traditionally used as a sugar crop and is known to adapt well to dry and hot climates due to its deep proliferated root structure. Therefore, it has been shown to be competitive with conventional bifofuel crops in terms of theoretical ethanol and lignocellulosic dry matter yield. Seeds of the Gulseker Sweet Sorghum variety were obtained from the Maize Research Institute, Sakarya, Turkey. Bitlis province was selected for testing the model plant because of the high sunshine duration and the fast growth of the plants thanks to the high photosynthetic capacity of the sorghum plant.

Soil Sampling and Characterization

The experiment was conducted at directly farmers field located in Tatvan district of Bitlis province (GPS 38.509441 N, 42.341652 E, and 1690 m above sea level) in the spring summer growing season of 2021. The experimental soil was sampled from surface horizons (0–20 cm) for basic soil analysis. Some selected physicochemical properties of the soil were given in Table 1. The soil was deep silt loam, mild alkaline and low in organic matter.

Table 1. Physicochemical properties of experimental soil and bio ash [10]

Parameter	Bitlis soil	Biomass ash (BA)
pH	7.45±0.04	13.04±0.20
EC (dS m^{-1})	0.34±0.02	27.43±0.55
Organic matter (%)	1.16±0.03	1.98±0.01
Kjeldahl N (%)	0.10±0.07	ND
P (mg kg^{-1})	45.94±1.15	13212±1.56
K (mg kg^{-1})	83.66±2.40	17554±2.56
Ca (mg kg^{-1})	390.00±8.80	32724±1.23
Mg (mg kg^{-1})	180.70±2.10	5385±1.19
Fe (mg kg^{-1})	29.04±1.25	2563±2.46
Mn (mg kg^{-1})	32.38±1.87	950±1.09
Zn (mg kg^{-1})	2.94±0.16	1222±1.62
Cu (mg kg^{-1})		67±0.86

Values are the mean±standard deviation of three samples, each measured in triplicate. EC: Electrical conductivity; dS: DeciSiemens; ND: Not detected.

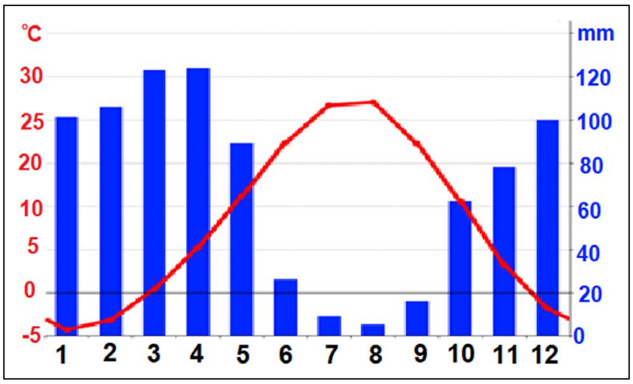

Figure 1. Long-term average precipitation, highest and lowest air temperatures for the years 1959–2021 in the province of Bitlis.

Meteorological Conditions

The experimental area is located in Bitlis province in eastern Turkey, where according to the Koeppen classification, the climate is Aas (continental dry and hot in summer), as it has high temperatures, low precipitation and relative humidity between 33 and 43% during the experimental period. The summer months are characterized by low precipitation and relatively longer hours of sunshine (12.2–13.0) per month. The average long-term monthly temperatures and precipitation for the period from 1959 to 2021 are shown in Figure 1.

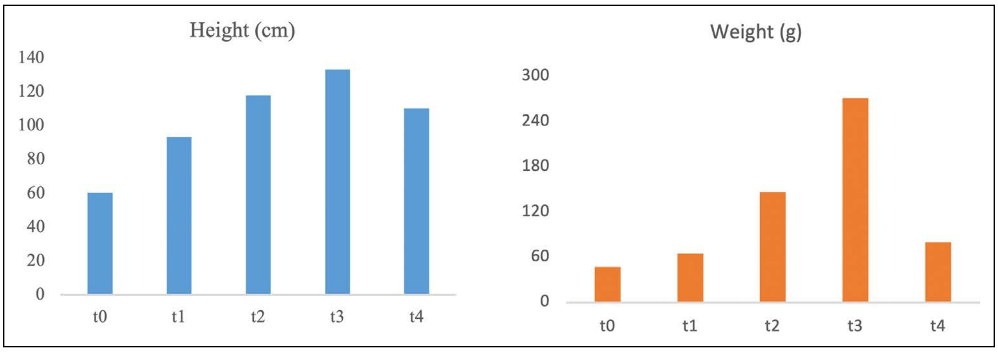

Figure 2. Biomass yield parameters of sweet sorghum plant grown in continental climate conditions with BA vermicompost application – Height and Weight (T_0=0.0%, T_1=3.5%, T_2=7.0%, T_3=10.0% biomass ash and vermicompost, T_4=fertilizer-free control).

According to the data obtained, the average amount of precipitation is 1046 mm, with most of it falling in spring and winter. The average amount of precipitation during the growing period of sweet sorghum (May-September) was 33 mm. The highest temperature during the growing season was recorded as 29.3 °C in August [23]. Rainfall during the growing season was insufficient to meet the plant's water needs. Therefore, weekly drip irrigation was applied at 10 mm per irrigation cycle.

Treatments and Field Design

Five different fertilization treatments were tested: T_0 (vermicompost, without BA); T_1 (vermicompost with BA, NPK content 3.5%); T_2 (vermicompost with BA, NPK content 7.0%); T_3 (vermicompost with BA, NPK content 10.0%); and T_4 (control, without fertilizer). Seeds were first germinated in seedling viol, and then the germinated plantlets were transplanted on the 5×3 m cultivation area at 30 cm spacing. Vermicompost was applied as basal fertilizer before sowing along the planting rows.

Brix Measurement

After plant harvest, 5 plant stems were pressed to extract the juice using a sugarcane 2-roller press. Then the Brix (%) values (Fig. 3) of juice were determined by using a handheld refractometer. The Brix counter was set to zero with distilled water and measured by taking a small amount of juice into the counter [14]. It was assumed that the sugar content in juice was equal to 75% of Brix [24].

Calculation of Sweet Sorghum Yield Data

Sweet sorghum plants, which were harvested by leaving a stubble height of 5 cm from the planting area of the sweet sorghum plant, were weighed (Fig. 4), and then the branches and leaves were separated and the leafless stem weight was noted. The stem thickness of the plants was measured with the help of caliper from a height of 30 cm from the ground and recorded. The plant samples brought to the laboratory environment were dried in an oven at 70 °C and their dry weights were

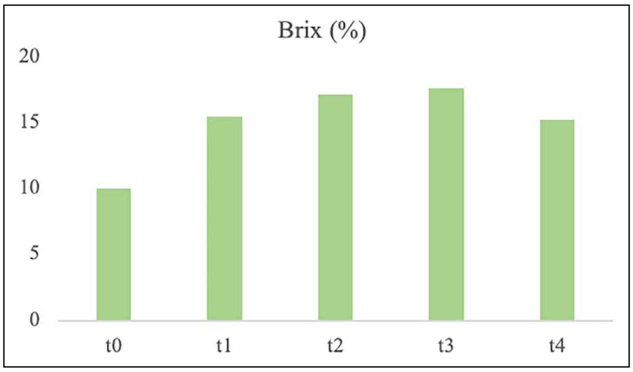

Figure 3. Biomass yield parameters of sweet sorghum plant grown in continental climate conditions with BA vermicompost application- Brix (%) (T_0=0.0%, T_1=3.5%, T_2=7.0%, T_3=10.0% biomass ash and vermicompost, T_4=-fertilizer-free control)

weighed. Calculations were made with the help of the following formulas (1), (2), (3) with the data at hand [25].

$$\text{Fluid Rate: } \frac{(Leafless\ stem\ weight\ (kg) - dry\ weight(kg))}{Leafless\ branch\ weight\ (kg)}\ x\ 100 \quad (1)$$

$$\text{Cane Yield (kg da}^{-1}\text{): } \frac{wet\ weight\ (kg)}{planting\ area(da)} \quad (2)$$

$$\text{Juice Yield (L da}^{-1}\text{): } \frac{Liquid\ Amount(L)}{planting\ area\ (da)} \quad (3)$$

Statistical Analysis

Each experiment was performed according to a completely randomized design with three replicates per amendment. The experimental data are subjected to the analysis of variance (randomize complete block design) by using the Statgraphics Centurion version of XVI (Statpoint Technologies Inc., Warrenton, VA, USA). Means that differed significantly are separated by using Tukey's Honestly Significant Difference (HSD) test at p 0.05 [3].

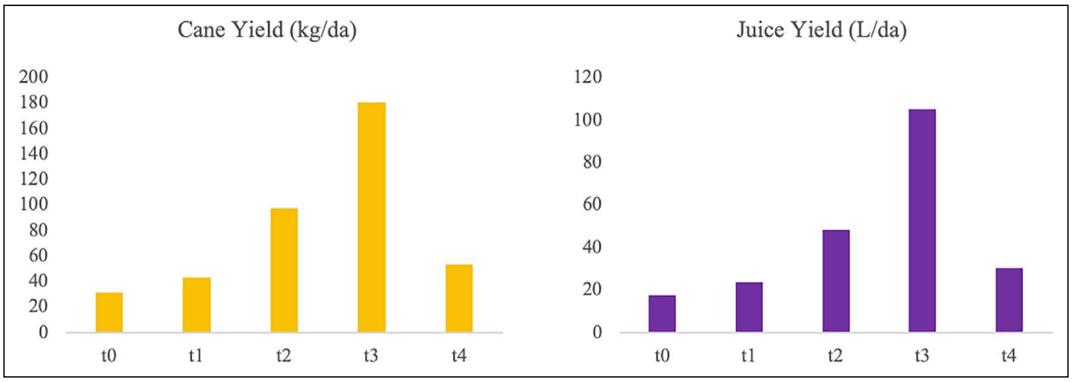

Figure 4. Biomass yield parameters of sweet sorghum plant grown in continental climate conditions with BA vermicompost application- Cane Yield and Juice Yield (T_0=0.0%, T_1=3.5%, T_2=7.0%, T_3=10.0% biomass ash and vermicompost, T_4=fertilizer-free control).

RESULTS AND DISCUSSIONS

Characterization of Biomass Ash and Experimental Soil

Total elemental composition analysis of biomass ash was done by ICP-MS. According to the analysis results, it was recorded as 32724, 17554, 13212 and 5385 mg kg^{-1} for calcium (Ca), potassium (K), phosphorus (P) and magnesium (Mg), respectively (Table 1). Biomass power plant ash includes forest waste, agricultural products and poultry bedding material as content. In previous studies, the most abundant elements in biomass ash content were recorded as calcium and potassium. Due to the presence of alkaline compounds, the pH value was recorded in the range of 12–13. The use of ash produced by biomass combustion as an additive to the composting process is envisaged as a potential solution to the most common critical problems [26].

Plant Growth Parameters

As a result of applications made for varying levels of biomass ash vermicompost, weight, height, sugar content (Brix), cane and fruit juice yield of sweet sorghum plant were examined under continental climate conditions. The averages of the parameters among the BA ratios in vermicompost applications containing BA ash in continental climate conditions are presented (Fig. 2). Brix % rates are higher than other applications as T3>T2. The Brix ratio of the plant in continental climate was brought to the range of 17–18% with BA vermicompost fertilization. Nitrogen (N) and Potassium (P) fertilized two different varieties (Rio and Keller) sweet sorghum plant obtained 18% Brix rates with different amounts of N and P applications [17].

In vermicompost applications containing BA ash, an increase in plant height was observed regardless of the ratio. The height of a sweet sorghum plant is directly proportional to its biomass yield. The plant height is between 60–133 cm and it is T3>T2>T4>T1>T0 respectively. Plant height is generally controlled by maturity and internode length. The longer the plant stays vegetative, the more leaves and height it makes. Typically, the stems contain 12–22% sugar. Although a positive relationship has been established between height and sugar accumulation, studies have shown that high sugar concentration is not only proportional to height, but it is possible to breed short and high sugar strains [27].

Height and Weight

The crop productivity of sweet sorghum plant is related to the plant population per unit area. However, wide or narrow spacing does not have a clear effect on crop performance [28]. The height of the sweet sorghum plant is mainly estimated from the maturity of the plant and the length between the nodes. Generally, late blooming plants appear to be taller than early blooming plants. Plant height of sweet sorghum is highly correlated with biomass yield [27]. The cluster that emerges while the sweet sorghum plant matures stops its lengthening. It has been reported that sugar accumulation increases after plant height stops [29]. It has been shown that 180 kg ha^{-1} urea application of the plant at physiological maturity increased the stem height by 12.65% [17]. Height and weight information of sweet sorghum plant grown in Bitlis climate conditions are given in the graphics in the figure. According to the data obtained, when the development of sweet sorghum plant is examined according to the amount of vermicompost applied, the best height is 133.33 cm in T3 (10% biomass ash and vermicompost) application. Sweet sorghum length was measured as 60.33 cm in T0 (0.0% biomass ash and vermicompost) application.

When the plant weights of the sweet sorghum plant with vermicompost application were examined, the order T3>T2>T4>T1>T0 occurred. Depending on the plant height, T3 (10% biomass ash and vermicompost) application contributed to the plant being heavier.

Brix (%)

Because of the presence of inverted sugars (glucose and fructose) the sweet sorghum juice is not commonly used for crystallized sugar production due to the difficult crystallization. However, fermentable sugars of juice offer an excellent potential for yeast fermentation to produce bioethanol. It has been reported that sugar accumulation increased rapidly after the internode elongation ceased after the sweet sorghum plant had clustered. However, the data obtained show that sugar accumulation is dependent on internode maturation rather than cluster formation [29]. When growing sweet sorghum, it is important to measure the Brix value frequently so that the growth trends of the plant can be analyzed. It helps us see how the quality of the crop improves during ripening, thus helping to find the right time to harvest the crop. Regardless of the ratio, the measured Brix remained in a narrow range of 10–17.6% in the vermicomposting application prepared with a mixture of biomass at different rates. Although positive results on plant growth were demonstrated in the previous N fertilization application, no improvement in Brix ratios was recorded [18].

Cane Yield and Juice Yield

The sugar contained in the plant is one of the most important properties of interest to growers, and research focuses on sugar accumulation and enzymes. Fermentable sugars, mainly including sucrose, glucose and fructose, are the main ingredient in sweet sorghum stalks for bioethanol production [15]. As a result of a 3-year study to determine the optimum N fertilization rate for the production of two common sweet sorghum varieties, the development of sweet sorghum was significantly affected by N application [18].

The volume of juice is a function of the stem volume depending on the stem height. Cane yield and juice yield yields are also promising in T2 and T3 applications, where the best yields in height and weight are obtained.

Transforming BA ash, which has a high plant nutrient content, into a fertilizer form that can be used by plants by the vermicompost method and fertilization at different rates, the relationship between the amount of fertilizer for the growth of sweet sorghum plant is evaluated, and T3 and T2 applications between cane and fruit juice yields are much higher than other fertilization amounts. reached

When the available data for the sweet sorghum plant, which has the ability to produce high biomass, are examined, the application of T3 (10% biomass ash vermicompost) is 70% higher than the application of T4 (without fertilizer).

CONCLUSIONS

Sweet sorghum plant, which is among sustainable green bioenergy crops, makes a potential contribution to future energy demand. With the interconnection between energy and sustainable development, sweet sorghum offers multiple benefits to both food, feed and energy security and environmental challenges such as water availability, carbon neutrality and ecosystems sustainability, if properly planned and managed. In the present study, in order to improve the existing production methods, an alternative solution was proposed in the Bitlis ecological conditions.

Biomass ash vermicompost was produced and tested as a sustainable fertilizer alternative for sweet sorghum production in Bitlis continental climate conditions. As a result of the analyzes made on the harvested stems to determine the post-harvest changes, the average best yields of different parameters were listed as T3>T2>T4>T1>T0. The plant heights were 60.33, 93, 118, 133.33, and 110 cm for the T0, T1, T2, T3, and T4, respectively. Average plant height positively correlated with the plant weights. The plant sugar yield and Brix values varied between 10–17.6% in tested treatments. Although the application of fertilizer at high rates shows positive results on sweet sorghum plant, the harms of excessive application to the environment are undeniable. It is promising that biomass yield can be improved with the application of BA vermicompost, which is preferred due to advantages such as low input requirements in Bitlis climatic conditions where the amount of dry and water is limited.

In sweet sorghum production, cane yield is 31–180 kg/da and juice yield is 17–105 L/da. Vermicompost has been investigated as an alternate source of conventional chemical fertilizer; the results revealed the significant effect of vermicompost on plant growth, yield, and quality parameters of the products. The vermicompost and crop growth experiments have shown that it is feasible to obtain nutrient-rich vermicompost by adding BA to bio-waste cow dung and vermicomposting of those materials back into the production cycle of biomass energy crops solves the problem of waste disposal, thus minimizing environmental pollution.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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