International Journal of Design & Nature and Ecodynamics
Vol. 18, No. 3, June, 2023, pp. 741-746
Journal homepage: http://iieta.org/journals/ijdne

Growth Response and Sugar Accumulation in First Ratoon Sweet Sorghum: Effects of Biochar and Shoot Number Manipulation

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https://doi.org/10.18280/ijdne.180328

Received: 24 February 2023
Accepted: 12 May 2023

Keywords:
biocharcoal, growth, number of shoot, sweet sorghum, ratoon

ABSTRACT

Sweet sorghum stems contain sap rich in lignocellulose and saccharides, making the plant a valuable source of high-quality forage, ethanol, and food products. This study aimed to investigate the effects of biochar application and shoot number manipulation on the growth response and sugar content of stem sap in first ratoon sweet sorghum. A Completely Randomized Block Design (CRBD) was employed, and data were subjected to an analysis of variance (ANOVA) at a 95% confidence level. In cases of significant differences, Duncan's Multiple Range Test (DMRT) was conducted for post-hoc comparisons. Results demonstrated a significant interaction between biochar application and shoot number manipulation on sugar content in the stem sap. Biochar application had a non-significant effect on the number of leaves and leaf area index, while shoot number manipulation exhibited a non-significant influence on stem diameter and seed weight per plant. These findings contribute to the understanding of optimizing growth and sugar accumulation in first ratoon sweet sorghum, potentially enhancing its applications in forage, ethanol, and food industries.

1. INTRODUCTION

Sorghum (*Sorghum bicolor* (L.)) a highly drought-resistant plant, distinguishes itself from other cereals due to its adaptability to dry and marginal environments. Sorghum is an attractive multipurpose crop in drought-prone regions in the context of food, feed, and bioenergy feedstock production [1]. This trait makes sorghum a promising candidate for cultivation in Indonesia, particularly for enhancing the productivity of marginal and arid lands [2]. The plant's efficient carbon metabolism allows it to thrive in the most challenging environments [3]. As reported by study [4], sorghum exhibits significant tolerance to drought, resistance to waterlogging, and favorable performance in infertile soil compared to other crops. Its potential as an alternative food, forage, and energy source, particularly sweet sorghum with high starch content, has garnered increased attention.

Environmental factors such as humidity, temperature, light, and water availability play a crucial role in the growth and development of sorghum plants in arid regions. Fluctuations in surface temperatures can adversely impact sorghum crops and reduce their yield potential. Generally, sorghum requires an optimum temperature of 21-35°C for germination, 26-34°C for vegetative growth, and 21-35°C for reproductive growth [5]. Primarily cultivated in drier environments on shallow and deep clay soils, sorghum demonstrates tolerance to alkaline soils and can be grown in pH ranges of 5.5 to 8.5. Water requirements depend on the growth stage and environment; typically, medium to late-maturing grain sorghum cultivars require 450-650 mm of water during the growing season. Sorghum exhibits the highest water-use efficiency under dry conditions (5.99 kg/m³) [6].

First ratoon sorghum yields are generally lower than those of the primary crop due to differences in agronomic characteristics and reproductive systems [7]. Research by Aqil [8] suggests that sorghum crops can be grown within ratoon systems, albeit with lower productivity than primary crops. Ratoon sorghum also demonstrates reduced productivity compared to seed planting [9]. Sweet sorghum, characterized by a unique source-sink system with two sinks (stems and seeds), stores photosynthates in the form of soluble disaccharides like sucrose in its stems. As the plant matures, assimilated carbon is used to synthesize insoluble carbohydrates (cellulose) and sucrose, which are stored in stems and seeds (as starch). Stems contain sugar-rich juice, bagasse waste with lignocellulose, and seeds with starch [10]. The sugar content of sweet sorghum stalks ranges from 14-23% Brix according to study [11], while Super 1 and Super 2 varieties exhibit potential sap content between 13.6% and 18.4% [12].

Enhancing soil fertility is essential for agricultural production in dry zones, where soil nutrient deficiency, insufficient rainfall, and elevated temperatures pose significant challenges [13]. Dry land in Indonesia has high potential, but low fertility. The addition of organic matter to the soil is very important because organic matter in the soil can make the soil more available or more fertile. Efforts to improve soil quality and fertility include the addition of ameliorant ingredients such as biological fertilizers and biochar. Organic matter is given regularly, so that the organic content in the soil is sufficient, balanced, and reduces the loss of organic matter from the soil, especially degraded soil. Soil nutrient scarcity and variable rainfall impede sorghum production [14]. Commonly-used fertilizers include urea and biochar.

Biochar, a stable soil conditioner suitable for dry land, serves as an organic matter source in soil management aimed at restoring and improving soil fertility. Biochar application has been explored as an option for conditioning soil in sorghum cultivation. By altering the chemical, biological, and physical properties of the soil, biochar significantly impacts soil fertility. Biochar quantity and quality are influenced by the type of raw material used [15]. Nitrogen and potassium are among the essential nutrients required by plants in large quantities [16]. By increasing the population of first ratoon sorghum through shoot thinning, it is anticipated that the population will improve relative to the primary crop. Planting density in ratoon sorghum plays a critical role in achieving higher grain yields and better quality [17]. Consequently, this research aims to investigate the effects of biochar application and shoot number manipulation on growth response and sugar content of stem sap in first ratoon sorghum.

2. MATERIAL AND METHOD

This sorghum research was at Cabeyan, Bendosari, Sukoharjo. The structure of the soil in Cabeyan village is clay. The type of soil in the research area is Grumusol soil. The microclimate in the research area includes daily rainfall of 336.75 mm, temperature at the time of research of 29°C, and humidity of 90-95%.

This material used, sorghum using super variety, biochar. The equipments used were planting tool, hand refractometer brix, vernier caliper, balance, and meter.

The research methods used is an environmental design is a Completely Randomized Block Design (CRBD) with 2 treatment factors. The first factor was biochar at four levels: 0 ton/ha, 2.5 tons/ha, 5 tons/ha, 7.5 tons/ha. The next factor is different number of shoots at four levels: 1, 2, 3, 4 shoots. Based on the design, 16 treatment combinations were obtained and 3x repetitions were carried out to obtain 48 experimental units.

Application of biochar by making an array around the planting (making an array between two rows of plants) according to the treatment. The spread of biochar is done evenly and then covered again with soil to reduce the risk of being transported by the flow of water when it rains. Provision of biochar adjusted to the treatment given.

The selection of shoots that are maintained/ratoon is by choosing shoots that grow to have a same height. Choose shoots that grow on stems that have been squeezed and take shoots/cut shoots that are not used according to the treatment given 1 shoot, 2 shoots, 3 shoots and 4 shoots. The selection of sorghum shoots must be representative of the population growing in the seed plots.

Sorghum plant growth was observed, namely the number of leaves, leaf area index and stem diameter. In addition, the brix value of the sugar level of stem sap in the first sorghum ratoon was also observed. Growth observations were carried out every 2 weeks until the plants were seven weeks old after cutting (7 weeks), while the brix sugar level of stem sap value was observed at 12 weeks using a hand refractometer.

The data gotten were processed using anova test at confidence interval of 95%. Test was carried out for significant difference to see the differences between treatments with the DMRT at the level of 5%.

3. RESULT AND DISCUSSION

General conditions of research

The research was carried out on the land of Cabeyan Village, Bendosari District, Sukoharjo Regency. Located at the east end of 110° 57' 33.70" E, the west end of 110° 42' 6.79" W, the north end of 7° 32' 17.00" N, and the south end of 7° 49' 32.00" LS. The research site is located at an altitude of 120 meters above sea level. The total area of Sukoharjo Regency is around 46.666 ha.

The climatic conditions at the time of the study had an average rainfall of about 336.75 mm with an average daily temperature of 23-34°C. It has an annual humidity of 75%. The type of soil in the research area is classified as grumusol soil. This type of soil is classified as clay/clay with a dark color and has heavy physical properties. The paddy field used for the study has an area of about 500 m^2 and has a slope of about 2-5%.

Number of leaves

Leaves play an important role in the process of photosynthesis. In general, leaves are green because they have a green substance or chlorophyll, the green color of the leaves has a main function, namely as a catcher of energy from sunlight for photosynthesis. Converts carbon dioxide and water into carbohydrates and oxygen with the help of sunlight. The number of leaves will affect the amount of assimilate produced, which in turn affects the formation of leaves and other plant organs. Leaves contain chlorophyll which is needed in the process of photosynthesis, so the more the number of leaves, the higher the photosynthetic results.

Table 1. The impact of biocharcoal on number of leaves

Biocharcoal	Number of leaves
0 ton/ha	7.9 a
2.5 ton/ha	8.3 a
5 ton/ha	9.0 b
7.5 ton/ha	9.4 b
Averages	8.6

Note: Numbers taken after by the same letter within the same column are not essentially diverse within the DMRT test at a 95% certainty level

Data in Table 1 shows that the interaction between biochar and number of shoot has not had a significant effect, while the biochar a significant impact on a number of leaves. Without the application of biochar the number of leaves obtained was 7 leaves. The biochar 5 ton/ha gave the best number of leaves, which was 9 leaves. The amount of biochar added to the soil affects the level of plant productivity [18].

That biochar is able to absorb nutrients and water so that nutrients can be available to plants. In addition, biochar is able to improve and optimize plant growth and production and reduce the amount of nutrients lost due to leaching. By providing biochar, it is able to provide a habitat for soil fungi and microbes thereby increasing the biological fertility of the soil. Biochar is a carbon-rich solid formed from organic residues by pyrolysis.

The availability of sufficient nutrients is able to help the formation of the vegetative part of the plant, the wider the leaf area formed, the more chlorophyll produced by the plant. So that the increased photosynthesis process can increase plant biomass which can increase production from plants. The increase in the number of leaves was caused by the formation of leaves influenced by the absorption and availability of nutrients. The number of leaves is related to the nutrients present in the soil and absorbed by plants through the roots.

Leaf Area Index (LAI)

Leaves are the main vegetative organs of plants, as a place for photosynthesis, plant transpiration, air exchange, and a place for regeneration of plant organs, as well as determining the leaf area index of plants. The Leaf Area Index/LAI is also an important indicator for identifying the productivity of agricultural crops. Leaf area index is the result of a comparison between the total leaf surface area and the area of the land area covered by the plant canopy (canopy).

Table 2. The impact of biocharcoal on leaf area index

Biocharcoal	LAI
0 ton/ha	1.44 a
2.5 ton/ha	1.77 b
5 ton/ha	1.79 b
7.5 ton/ha	1.88 b
Averages	1.72

Note: Numbers taken after by the same letter within the same column are not essentially diverse within the DMRT test at a 95% certainty level

Table 2 shows that the interaction between biochar and number of shoot has not had a significant effect, while the biochar a significant impact on a leaf area index. The biochar 2.5 ton/ha results in the LAI significantly different from that without biochar. And than, the biochar 7.5 ton/ha gave the best leaf area index, which was 1.88. LAI is very important to know the intensity radiation intercepted by the leaves so that can be used for value estimation the biomass.

Increasing the LAI value will increase Net Assimilation Rate, namely the ability of plants to produce dry matter through the assimilation process per unit leaf area per unit time. The factors that influence the LAI value are the growth phase, plant density and the supply of nutrients including N which affect the size of the leaf area.

LAI in the leaves of first ratoon sorghum is affected by the dose of biochar given, in which wood biochar can improve the C-organic content of soil. High C-organic content can increase plant productivity, because the plant can absorb high nutrient for the optimum growing process.

According to study [19] the application of charcoal can increase P, K, Ca, Na, and Mg contents of soil. According to study [20] stated that biochar directly becomes the source of P and K substances. In addition, it can improve P availability through increasing pH of soil and ameliorating Metal-P complex [21]. LAI value is optimum, so that the leaves effectively absorb sun radiation in photosynthesis process.

The photosynthesis process results in larger photosynthate, allowing for the formation of larger plant organs like leaves and roots that will produce larger dry materials. With an increase in leaf area, it means that it'll increase the absorption of light by the leaves, at that point the photosynthesis process will increase and produce assimilate which is able be utilized as a source of growth energy in forming vegetative organs in the growth stage, whereas within the generative stage the assimilate is stored in the tissues of the vegetative organs. will be transferred for the formation of regenerative organs, such as seed filling [22]. The climatic conditions at the time of the study had an average rainfall of about 336.75 mm with an average daily temperature of 23-34°C. It has an annual humidity of 75%.

Stem diameter

The stem of the plant grows very fast vegetative period. Stems use some of the carbohydrates formed by the plant for the development of cells in the cortex and systems vessels resulting in an increase in stem diameter. Stem enlargement results from cellular enlargement and division. Nitrogen substance is one of nutrients contributing to photosynthesis to yield photosynthate, one of which is carbohydrate.

The carbohydrate was used as energy source for vegetative growth activity, one of which is stem diameter enlargement. As for those that affect the growth of sorghum stem diameter such as maturity at harvest, sorghum varieties, and environmental factors. Stem diameter affects the production of biomass and seeds in sorghum which is useful for supporting panicles and resistance of sorghum from collapse. By having good stems, plants become stronger and do not collapse easily so that they can carry out their physiological functions.

Table 3. The impact of number of shoots on stem diameter

Shoots	Stem diameter (mm)
1 Shoot	15.44 b
2 Shoots	13.47 a
3 Shoots	12.27 a
4 Shoots	11.93 a
Averages	13.28

Note: Numbers taken after by the same letter within the same column are not essentially diverse within the DMRT test at a 95% certainty level

Table 3 shows that the stem diameter of first ratoon sorghum with 1 shoot has highest diameter, which was 15.44 mm compare with 4 shoots, which was 11.93 mm. The lower the number of shoot treatment, the more optimum is the growth, because there is no competition in the plant growth. Nutrient can be retained ideally and so has an affect on big diameter of stem. Stem diameter was affected by the main effects of the cultivar and harvesting stage [23]. The influence of genetic factors is more dominant in determining stem diameter than environmental factors.

But the number of plants per hole can generate competition between similar plants for the absorption of sunlight, nutrient, water, and growing space for the plant growth. The plant density of one plant/planting plant has the most elevated value compared for the other. It is because the competition for water, solar energy absorption, nutrient absorption and growing space in the sorghum plant. Sorghum planted with higher density will result in higher competition and lower sunlight absorption. Sorghum planted with higher density will cause stress on vigor and inhibit the development of new shoots. The plant thickness influenced the photosynthetic rate and carbon absorption capacity of takes off by impacting the plant wholesome status and light dissemination within the populace [24].

Seed weight per plant

Seed weight per plant is strongly influenced by genetic factors such as leaf shape, number of leaves, and leaf length or width which will affect the process of plant photosynthesis. the number of shoots affects the seed weight per plant of first ratoon sorghum. Seeds are the result of plant metabolism, where the metabolism can take place properly if sufficient nutrients are available. If the availability of water is limited, the nutrients that are soluble and can be absorbed by plants become less. As a result, metabolism is disrupted and seed yields decrease.

The process of opening and closing stomata is related to the process of photosynthesis. Photosynthesis requires CO2 which enters the plant through the stomata. If the availability of water and nutrients is limited, the process of opening and closing stomata is disrupted and results in hampered photosynthesis. As a result, photosynthate is reduced and affects the yield of plants, one of which is seeds.

Table 4. The impact of number of shoots on seed weight per plant

Shoots	Seed weight per plant (g)
1 Shoot	22.63 b
2 Shoots	21.20 b
3 Shoots	17.50 a
4 Shoots	17.34 a
Averages	19.66

Note: Numbers taken after by the same letter within the same column are not essentially diverse within the DMRT test at a 95% certainty level

Table 4 shows that the result is that 1 (one) shoot provides seed weight per plant of first ratoon sorghum significantly different from seed weight per plant in 3 and 4 shoots. The more the number of shoots growing, the lower is the seed weight per plant. The nutrient, water, and light highly affect metabolism in flower and seed development in plant. Similar economic crops such as sorghum with the Numbu variety when the seed weight per ratoon sorghum per plant was adjusted was 80.43 g, this means that the seed weight is influenced by the genetics of the plant. So that, the formation and filling of seeds is determined by the plant's genetic ability in each plant related to the source of assimilate and the provision of nutrients to the plant. Sorghum seed size is inherited from genetic factors that affect seed weight. Seed size can affect seed weight. The smaller seeds are formed due to aging and faster seed ripening.

And then, the nutrients absorbed by sorghum ratoon which grows with 1 shoot compared to 4 shoots will be better if it is on 1 shoot because all the nutrients in the soil can be absorbed by sorghum ratoon. Meanwhile, 4 shoots will experience competition in absorbing soil nutrients.

The competition between plants for light, water, and supplements gets to be basic and can lead to decreased crop yields [25]. At that point taken after by other natural variables such as pests and diseases that attack. Bird attacks can diminish grain yields by up to 73%. Meanwhile, according to study [26] Anthracnose disease can reduce sorghum seed yields by up to 86%.

Sugar level of stem sap

Sugar sap level of sorghum stem will increase along with the older age of plant up to seed ripening phase. The sugar sap level of stem will achieve maximum level when sorghum plant has entered into physiologically mature (ripe) phase (120 day after planting).

Nira is a liquid contained in the stems of plants that contain sugar and other substances (non-sugar) such as water, fiber, organic and inorganic substances. The brix sugar content of sweet sorghum stem sap ranges from 9-15%. The sugar content of brix derived from stem sap can be used as a criterion for selection of good sweet sorghum genotypes for production.

Table 5. The impact of biocharcoal and distinctive number of shoots on sugar sap level of stem

Treatment	1 shoot	2 shoots	3 shoots	4 shoots	Averages
0 ton/ha	10.07 d	6.33 a	13.20 f	12.13 ef	10.43
2.5 ton/ha	9.60 cd	13.47 f	12.00 ef	8.40 bc	10.86
5 ton/ha	13.47 f	10.33 d	11.07 de	13.07 f	11.98
7.5 ton/ha	13.27 f	7.73 ab	9.73 cd	9.67 cd	10.10
Averages	11.60	9.47	11.50	10.81	

Note: Numbers taken after by the same letter within the same column are not essentially diverse within the DMRT test at a 95% certainty level

An important character that can describe the potential of a sweet sorghum variety as a raw material for bioethanol is the level of sap. Table 5 shows that the interaction between the biochar and number of shoot doses significantly affects the sugar level sap stem.

The impact of giving biochar is such as increasing carbon absorption, improving soil structure. Biochar has its own advantages, such as rich carbon content, high cation exchange capacity, large surface area and structural stability. Reduce the loss of nutrients in the soil, absorb atmospheric carbon into the soil, increase agricultural productivity, reduce the bioavailability of environmental pollutants. so that the application of organic matter in the form of biochar will increase the C-organic content in the soil. That the C-organic content of the soil increased from 0.90% to 1.02%-1.07%.

The highest sugar sap level of first ratoon sorghum stem 13.47% brick occurs in the biochar 5 tons/ha with 1 shoot. The administration of organic material to dry land can improve soil aeration, root penetration, and water absorption, and can reduce land surface hardening. The plant’s need for nutrient is absolute; the nutrient deficiency will inhibit plant growth and decrease productivity. The application of biochar can increase the sap sugar level in sorghum stem. The sugar level of stem sap in 1 shoot is higher than that in 2, 3, and 4 shoots. Nutrition needed in sorghum with 1 shoot is absorbed more optimally compared with that in that with more 2, 3 or 4 shoots.

Sweet sorghum is a C4 Graminaceous crop with high biomass production that yields 3-6 t/hm^2 of grain and 45-75 t/hm^2 of sugar-rich stalks. The sap squeezing rate of sweet sorghum can reach 60%-70% and the sugar content in sweet sorghum juice is approximately 13-20 Brix. There are 43.6-58.2% soluble sugars and 22.6%-47.8% insoluble carbohydrates [27].

According to study [28] study found that bioethanol production is highly dependent on the quality of sweet sorghum plant, sap level of stem or carbohydrate content of seed. Sap level of stem has wide value interval, dependent on sweet sorghum plant variety. The sap sugar level of sweet sorghum stem ranges between 5.67% and 22.67%, while according to study [29] stated that total sap sugar level ranges between 9 and 20%. The yield increase from ratoons using biochar was 3%. then the difference between planting from seeds and planting ratoon sorghum is that ratoon sorghum uses sorghum plants grown from seeds harvested and then pressed during planting season 1 so that planting saves more costs and costs for cultivating the soil.

4. CONCLUSIONS

The result of research shows that the biochar application has in significant effect on number of leaves has value of 9 leaves at dose 5 ton/ha, on leaf area index has value of 1.77 at dose 2.5 ton/ha. The effect of shoot number on stem diameter of first ratoon sorghum has highest value 15.4 mm in 1 shoot and on seed weight per plant has value 22.63 g in 1 shoot. It results in interaction between application biochar and the number of shoot in the sugar level of stem sap in first ratoon sorghum stem of 13.47% brick at dose 5 ton/ha in 1 shoot.

ACKNOWLEDGMENT

The authors are grateful to Ministry of Education, Culture, Research, and Technology Republic of Indonesia for funding this research through the scheme of Master's Thesis Research for the fiscal year 2022.

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