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Promoting Sustainable Sorghum Production: The Role of Ratoon Cultivation and Fertilizer Management

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Abstract

This study investigated the biomass productivity of sorghum main crop, first ratoon, and second ratoon. A randomized complete block design was employed for the main crop experiment, with eight sorghum genotypes (NS2-19, NS2-102, NS2-109, NS2-111, NS2-140, IPB 4, IPB 8, and "Numbu") as the treatment factor. The ratoon crop was designed using a Split Plots Design with two treatment factors and three replications. The first factor was fertilizer treatment on the ratoon crops, with two levels: complete N, P, and K fertilizer (urea 133 kg.ha^{-1}, KCl 100 kg.ha^{-1}, and SP-36 100 kg.ha^{-1}) and N fertilizer only (urea 133 kg.ha^{-1}); this factor was arranged as the main plot. The second factor comprised eight elite sorghum lines, the same as those used in the main crop experiment, arranged as subplots. The results indicated that complete NPK fertilization and N fertilizer alone produced similar biomass productivity in sorghum ratoon crops. Among the genotypes, NS2-140 demonstrated the highest biomass productivity in the main crop, NS2-109 in the first ratoon, and NS2-19 in the second ratoon. The second ratoon exhibited the highest biomass yield compared to the main crop and the first ratoon.

Keywords: fertilization, forage genotype, ratoon crop, second ratoon

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench), a versatile crop with significant economic and environmental value, is a staple food for half a billion people worldwide, particularly in Africa and Asia. It serves as a crucial source of animal feed and biofuel (Tao et al., 2021), and its C4 photosynthetic pathway equips it to thrive in arid and semi-arid regions, demonstrating remarkable drought and salinity tolerance (Dehnavi et al., 2020). Its low input requirements and relatively high productivity make it a popular choice for farmers in resource-limited areas (Azrai et al., 2021).

Beyond grain production, sorghum biomass holds immense potential for bioenergy applications. Its stalks and seeds can be converted into pellets, briquettes, and bioethanol, providing a sustainable alternative to fossil fuels (Batog et al., 2020). Enhancing sorghum cultivation's productivity is essential to maximizing its economic benefits.

Sorghum offers numerous benefits, making it essential to strive for increased productivity. One way to achieve this is by implementing a ratoon system, which involves growing shoots from previously harvested plants. The ratoon system does not require seeds, only sufficient resources for shoot regeneration (Azizah et al., 2022). Cultivating sorghum using this ratoon system can enhance yield production, as sorghum plants possess the unique characteristic of being harvested once or multiple times (multi-cut harvest), commonly called ratoon system cultivation (Silva et al., 2022).

However, the ratoon cultivation of sorghum still has some limitations, with the main crop yield significantly higher than that of the ratoon crop. This discrepancy exists because only a few sorghum varieties currently available in the market are well-suited for the ratoon system. Consequently, this research was conducted using seven IPB lines and one national variety to identify varieties that are compatible with the sorghum ratoon cultivation system. These lines and varieties were selected for their high biomass production potential. Additionally, they were chosen because they are related to the "Numbu" variety, which is known for its suitability in ratoon cultivation. Meliala et al. (2017) highlighted that "Numbu" has the best ratooning ability among the five varieties tested. Effective plant cultivation techniques, such as fertilization, are crucial to address the challenges

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associated with ratoon system cultivation. Fertilization aims to meet plants' nutrient needs by adding organic and inorganic materials to the soil. Optimal nutrient availability, particularly nitrogen (N), phosphorus (P), and potassium (K), is expected to enhance plant growth and development (Mansyur et al., 2021). Zhou et al. (2022) suggested that using fertilizers, especially N, can increase sorghum production yields for both main and ratoon crops, thereby narrowing the yield gap between these crops. Istiqomah (2022) indicated that applying urea (N) fertilizer alone can enhance the yield of the first ratoon sorghum plant.

While fertilization offers significant benefits, the continuous use of chemical fertilizers can have detrimental effects on soil fertility. This research explored the use of complete fertilizers with N, P, and K and treatments using only N fertilizers. The goal was to achieve high biomass production in ratoon systems with minimal fertilizer application and to identify sorghum genotypes adaptable to cultivation patterns with low fertilizer inputs.

Material and Methods

This research was conducted at the experimental station of the Agricultural Instrument Standardization Agency, Center for Standard Testing of Biotechnology Instruments and Agricultural Genetic Resources (BSIP BIOGEN), Cimanggu, Bogor, West Java. The study was carried out from June to December 2023. Climate data for this study were obtained from BMKG (Indonesian Agency for Meteorological, Climatological, and Geophysics) Dramaga, West Java. The average climate conditions during the growing season are presented in Table 1. Main crop cultivation occurred from June to September 2023 and was harvested 73 days after sowing (DAS). The first ratoon was grown from September to October 2023 and harvested at 55 days after ratooning (HSR), while the second ratoon was cultivated from October to December 2023 and harvested at 64 HSR. Soil analysis conducted at the Testing Laboratory of the Department of Agronomy and Horticulture to assess the soil conditions of the research area is presented in Table 2. Soil samples were collected from three different points along the plant beds.

The main crop was grown using a completely randomized complete block design with one treatment factor and six replications prepared for subsequent ratoon crop experiments. The treatment factor for the main crop was sorghum lines (8): NS2-19, NS2-102, NS2-109, NS2-111, NS2-140, IPB 4, IPB 8, and "Numbu" varieties. This setup resulted in 48 experimental units, each consisting of ten plants that served as sample plants.

Land preparation for main crop cultivation involves several steps: tillage of the planting site, clearing the land of weeds or remnants of previous crops, liming, and applying manure. The planting distance used in this experiment was 60 cm x 15 cm. Replanting was performed one week after planting to replace plants that died or did not grow. Thinning was done two weeks after planting, leaving one plant per hole. Fertilizer application was carried out in two stages: the first stage at ten days after planting, and the second stage at four weeks after planting. The fertilization rates were 200 kg.ha^{-1} of urea, 100 kg.ha^{-1} of KCl, and 100 kg.ha^{-1} of SP-36. The variables observed in main crop cultivation included plant height growth rate, plant height, leaf number growth rate, leaf number, stem diameter, fresh biomass weight, dry biomass weight, Leaf greenness was measured using SPAD (Soil and Plant Analysis Development) chlorophyll meter.

Ratoon crop cultivation was designed using a split plot design with two treatment factors. The first factor was post-harvest fertilizer, which included two levels: complete N, P, and K fertilizer (urea 133 kg.ha^{-1}, KCl 100 kg.ha^{-1}, and SP-36 100 kg/ha) and N fertilizer only (urea 133 kg.ha^{-1}), which constituted the main plot. The second factor was sorghum plant lines, consisting of eight levels as the main crop, which formed the subplots. This design resulted in 16 treatment combinations, each replicated three times, leading to 48 experimental units. Each experimental unit contained ten plants that served as sample plants.

In this study, the ratoon system cultivation was implemented twice. First, the main plant was harvested, and the stem was cut approximately one node or 5-10 cm above the soil surface. The remaining stems were left to grow new shoots and were then cultivated similarly to the main crops. Second, the first ratoon plant was harvested and cut at the stem about one node or 5-10 cm above the surface where the first ratoon emerged. The remaining stems were left to grow new shoots and then cultivated as with the previous main plants. Fertilization in this study was conducted in two stages: one-third of the total fertilizer dose was applied ten days after the ratoon crops emerged, while the remaining two-thirds were applied when the plants were four months old. The variables observed in the ratoon crops were the same as the main plants, including plant height, number of leaves, stem diameter, fresh biomass weight, dry biomass weight, leaf greenness, brix content, and the number of ratoon crops. Biomass harvesting of ratoon crops was performed when the plants reached

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the maximum vegetative phase, characterized by the appearance of flag leaves.

The data collected were analyzed using variance analysis at the 5% level to determine if the treatments significantly affected the observed variables. If significant differences were found, further testing was conducted using the Tukey HSD test at the 5% level. Correlation and path analysis were performed to study the relationship between growth components and plant yield components. Data processing was done using the Microsoft Excel 2016 program and SAS software.

Result and Discussion

Vegetative Growth of The Main and Ratoon crops

The growth of main plants significantly impacts the growth of ratoon crops, as ratoon crops develop from the main plants previously cultivated. Observations of the eight sorghum genotypes used in this study revealed that genotypes had a significant effect on plant height growth rate, plant height, and the number of leaves (Table 3). Meliala et al. (2017) suggested that genotypes influence plant height and the number of leaves in sorghum. Purwanto et al. (2023) also indicated that agronomic characteristics, such as

Table 1. Climate data for June-December 2023

Month	Temperature (^{o}C)	Humidity (%)	Rainfall (mm per month)	Duration of exposure (%)
June	26.4	83.9	425.0	76.8
July	26.3	79.5	202.5	75.3
August	26.4	76.3	199.0	87.0
September	26.0	83.8	37.5	69.5
October	27.7	73.8	139.0	63.4
November	26.9	84.5	1063.5	47.6
December	27.2	81.0	392.0	47.7

Table 2. Soil chemical properties of the study area

Soil chemical properties	Test point 1*	Test point 2*	Test point 3*
pH H_2O	4.97	4.60	5.52
N-total (%)	0.16	0.21	0.24
Available P (ppm P_2O_5)	<0.08	<0.08	56.75
Potential P (mg P_2O_5/100 g)	105.97	131.39	156.18
Potential K (mg K_2O/100 g)	4.87	33.10	22.37

Notes: * point 1, 2, and 3 refers to the sampling location along the plant beds.

Table 3. Vegetative growth of different sorghum lines and cultivar

Treatment	Plant height growth rate (cm per week)	Leaf number growth rate (strandsper week)	Plant height (cm)	Leave number (strands)	Stem diameter (cm)
NS2-19	4.79ab	0.21	191.12ab	14.28ab	1.71
NS2-102	4.64ab	0.22	186.10ab	14.30ab	1.80
NS2-109	4.36abc	0.22	173.95abc	13.93b	1.75
NS2-111	5.14a	0.22	205.55a	14.27ab	1.76
NS2-140	4.82ab	0.23	193.47ab	14.95ab	1.85
IPB 4	2.91c	0.21	122.50c	13.98ab	1.85
IPB 8	3.45bc	0.23	139.70bc	15.47a	1.89
“Numbu”	4.97a	0.21	198.42a	14.02ab	1.75
P-value	0.000	0.217	0.000	0.030	0.259
CV (%)	18.60	7.98	16.65	5.70	7.39

Notes: CV is the coefficient of variance. Values followed by the same letter in the same column indicate results that are not significantly different based on the HSD test at $\alpha < 0.01$ (**) and < 0.05 (*).

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plant height, are influenced by plant genotypes. In this study, the six genotypes tested exhibited significantly different plant heights.

Genotypes IPB 4 and IPB 8 exhibited shorter plant height than the other genotypes (Table 3). This difference in plant height may reflect the plants' capacity to adapt to their environment. Tall plant genotypes are well-suited for forage production as animal feed (Birhan et al., 2020), while shorter plant genotypes are often recognized for drought tolerance (Seyoum et al., 2019).

The interaction between fertilizer treatments and genotypes did not significantly affect the vegetative characteristics of the first ratoon crops (Table 4). This lack of interaction suggests that all genotypes responded similarly to fertilizer application regarding vegetative traits. However, in the second ratoon, the interaction between fertilizer treatment and genotype significantly influenced the number of leaves (Table 4).

The interaction between fertilizer treatment and genotype on the number of leaves on the second ratoon is presented in Table 5. The results indicated that the NS2-19 genotype, when fertilized with N alone, had the highest number of leaves at 12.63 strands per plant. In contrast, the IPB 8 genotype with NPK fertilization had the lowest number of leaves at 9.87 strands per plant. This difference can be attributed to excess phosphorus (P) in soil from NPK fertilization, which can inhibit plant growth. Soil test results (Table 2) show that P availability in the soil is variable, ranged from 0.08 to 56.75 ppm P_2O_5. Therefore, P availability at some points of the plant bed was already optimal (56.75 ppm). Additional P fertilizer can lead to nutrient excess which impedes leaf growth, as shown in Table 5. IPB 8 genotype with NPK fertilization had the lowest number of leaves compared to fertilization with N only (Table 5). Lukman (2010) noted that excess P can inhibit plant growth, as evidenced by observations of mangosteen seedlings. In this study, treatments with P at 25 ppm (59 strands/plant) and 50 ppm (58 strands/plant) resulted in more leaves compared to treatments with P at 100 ppm (45.33 strands per plant), 200 ppm (49.17 strands/plant), and 400 ppm (37.67 strands per plant).

The fertilizer treatment did not show significant differences for all vegetative characteristics of the first and second ratoon crops (Table 4). This suggests that fertilization with nitrogen (N) alone is sufficient for the vegetative growth of sorghum plants, as N is required in relatively higher amounts during the vegetative phase as compared to phosphorus (P) and potassium (K). Iswiyanto et al. (2023) similarly noted that during the vegetative phase of edamame plants, N nutrients are more crucial than P and K. Moreover, P nutrients are primarily needed in the plant's generative phase.

Table 4. Vegetative growth of sorghum ratoons

Treatment	Number of ratoons		Plant height (cm)		Plant height changes (%)	Leaf number (strands)		Stem diameter (cm)	
	R1	R2	R1	R2		R1	R2	R1	R2
Fertilizer (F)									
NPK	5.23	6.21	171.26	213.73	25	11.06	11.31	1.50	1.43
N only	5.01	6.13	170.33	212.72	25	11.40	11.73	1.53	1.45
P-value	0.458	0.727	0.845	0.836	-	0.164	0.164	0.372	0.193
Genotype (G)									
NS2-19	4.95	5.73b	177.08a	228.17a	29	11.45a	11.77ab	1.54abc	1.45ab
NS2-102	5.17	5.87b	187.53a	234.87a	25	11.20ab	12.13a	1.55abc	1.50a
NS2-109	5.53	6.27b	187.97a	233.17a	24	11.17ab	12.05a	1.52abc	1.47ab
NS2-111	5.30	5.83b	176.63a	212.08ab	20	11.38a	11.33ab	1.47abc	1.42ab
NS2-140	5.07	5.38b	180.43a	217.92ab	21	11.83a	11.38ab	1.61ab	1.49a
IPB 4	4.32	6.08b	136.00b	186.55bc	37	9.82b	9.93b	1.40bc	1.41ab
IPB 8	5.50	8.57a	133.03b	162.53c	22	11.37a	11.13ab	1.39c	1.33b
"Numbu"	5.13	5.62b	187.68a	230.48a	23	11.60a	12.40a	1.64a	1.46ab
P-value	0.532	0.000	0.000	0.000	-	0.011	0.007	0.007	0.019
F x G	0.590	0.925	0.564	0.384	-	0.720	0.044	0.007	0.105
CV (%)	19.03	19.11	16.04	13.99	-	9.08	11.27	9.13	6.53

Notes: R= ratoon, CV= coefficient of variance. Values followed by the same letter in the same column indicate results that are not significantly different based on the HSD test at α < 0.01 (**) and < 0.05 (*).

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Schlegel et al. (2020) also reported that adding P fertilizer can enhance sorghum seed production during the generative stage.

The genotype treatment factor for the first ratoon crops significantly affected plant height, number of leaves, and stem diameter, while for the second ratoon, genotype differences influenced all vegetative characteristics (Table 4). Variations in sorghum genotypes can result in differing vegetative traits. Observations from the first ratoon showed that the NS2-109 genotype had the tallest plant, measuring 187.97 cm, whereas the IPB 8 genotype had the shortest height at 133.03 cm. Regarding the number of leaves, the NS2-140 genotype had the highest average, with 11.83 leaves per plant, while the NS2-109 genotype had the fewest leaves, averaging 11.17 per plant. For stem diameter, the “Numbu” genotype exhibited the largest diameter at 1.64 cm, while the IPB 8 genotype had the smallest diameter at 1.39 cm. Observations on the second ratoon crops revealed that the genotype IPB 8 had the highest number of ratoons growing at 8.57, while NS2-140 had the lowest average number at 5.38. Regarding plant height, NS2-102 exhibited the tallest plants, with an average height of 234.87 cm, whereas IPB 8 had the shortest height, averaging 162.53 cm. Regarding the number of leaves, the “Numbu” genotype had the highest average, with 12.40 leaves per plant, while IPB 4 had the lowest, with 9.93 leaves per plant. For stem diameter, NS2-102 had the highest average at 1.50 cm, while IPB 8 had the smallest diameter at 1.33 cm.

The variation in the first and second ratoon crops across different genotypes underscores the diverse characteristics of each genotype. For instance, the percentage difference in plant height between the first and second ratoon varied significantly among the genotypes (Table 4). This variation highlights

Table 5. Interaction between fertilizer treatment and genotypes on the number of plant

Treatment	NS2-19	NS2-102	NS2-109	NS2-111	NS2-140	IPB 4	IPB 8	“Numbu”
NPK	10.90abc	12.50ab	11.83abc	10.90abc	12.10abc	9.93bc	9.87c	12.43abc
N	12.63a	11.77abc	12.27abc	11.77abc	10.67abc	9.93bc	12.40abc	12.37abc

Notes: Values followed by the same letter in the same column indicate results that are not significantly different based on the HSD test at α < 0.01 (**) and < 0.05 (*).

Table 6. Leaf greenness and Brix level of the main and ratoon crops

Treatment	Leaf greenness			Brix levels (%)		
	Main crop	Ratoon 1	Ratoon 2	Main crop	Ratoon 1	Ratoon 2
Fertilizer (F)						
NPK	-	52.28a	47.49	-	9.68	9.45
N	-	50.82b	46.90	-	10.01	9.29
P-Value P	-	0.003	0.543	-	0.459	0.671
Genotypes (G)						
NS2-19	54.00a	52.65	47.87	10.46	9.38	9.86
NS2-102	54.12a	52.16	48.28	10.19	10.48	9.54
NS2-109	52.27ab	51.43	48.63	9.56	10.04	9.48
NS2-111	54.21a	50.43	46.56	11.06	8.87	9.53
NS2-140	53.86a	51.08	46.62	9.36	9.06	8.51
IPB 4	46.58b	50.51	43.45	7.77	9.08	9.50
IPB 8	53.85a	52.60	47.91	11.59	11.59	8.40
“Numbu”	55.50a	51.53	48.24	12.26	10.28	10.12
P-Value G	0.002	0.122	0.184	0.090	0.055	0.307
Interaction PxG	-	0.159	0.787	-	0.740	0.844
CV (%)	6.18	4.04	7.09	24.08	16.77	13.94

Notes: Leaf greenness is based on SPAD values. CV= coefficient of variance. Values followed by the same letter in the same column indicate results that are not significantly different based on the HSD test at α < 0.01 (**) and < 0.05 (*).

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the unique attributes of each genotype. Maftuchah (2021) noted that sorghum genotypes exhibit different characteristics, influencing plant height, number of leaves, stem diameter, number of tillers, and fresh and dry biomass weights. Similarly, Abood et al. (2021) reported that differences in the genetic structures of sorghum cultivars lead to variations in agronomic traits, such as plant height.

Main and Ratoon Plant Physiology

Observations of plant physiological characteristics in the main crop revealed that the genotypes only significantly affected the leaf greenness (Table 6). The greenness level was determined by measuring the leaf chlorophyll content of the leaves using the SPAD tool. The results showed variation in leaf greenness among the tested genotypes. The “Numbu” genotype exhibited the greenest leaves, with 55.50 SPAD units, while the IPB 4 genotype had the lowest at 46.58 SPAD units. This variation in leaf greenness between genotypes is attributed to differences in leaf chlorophyll content. Sundari et al. (2015) emphasized that leaf greenness is determined by the chlorophyll index, with higher chlorophyll content resulting in greener leaves.

Observations of the first and second ratoon crops revealed that the interaction between fertilizer treatment and genotype did not significantly influence the plant’s physiological parameters. The fertilizer treatment only affected leaf greenness in the first ratoon, whereas in the second ratoon, no significant effect of fertilizer treatment on physiological characteristics was observed. Additionally, genotype treatment did not affect the physiological characteristics of either the first or second ratoon crops.

Leaf greenness observations for the first ratoon showed that the NPK fertilizer treatment resulted in a higher leaf greenness level (52.28 SPAD units) than the N treatment alone, with a leaf greenness value of 50.82 SPAD units. This suggests that the NPK treatment leads to higher chlorophyll content than nitrogen alone, as leaf greenness correlates with chlorophyll levels. The observed differences in leaf greenness are likely due to the varying fertilizer compositions, where the addition of phosphorus (P) and potassium (K) may enhance chlorophyll synthesis, resulting in increased leaf greenness. These findings align with the research of Nyoki et al. (2016), which showed that applying P and K fertilizers significantly increased the greenness of soybean leaves due to enhanced chlorophyll content.

Biomass Yield of Main and Ratoon crops

Biomass yields from this study are presented in Table 7. Observations of the main crop indicated that genotypes only significantly affected the dry biomass weight of the plants. There was a noticeable variation in dry biomass weight across different genotypes. The NS2-140 genotype produced the highest dry biomass weight, reaching 124.90 g, while the IPB 4 genotype exhibited the lowest dry biomass weight of 89.19 g. The variation in dry biomass weight is primarily influenced by vegetative growth parameters such as plant height, stem diameter, and the number of leaves. This is consistent with the findings of Hadi et al. (2018), who noted that dry biomass weight is supported by plant height and plant stem diameter. Additionally, the correlation test results, shown in Table 8, confirm that the number of ratoons, plant height, number of leaves, and stem diameter are significantly and positively correlated with the dry biomass weight of sorghum plants.

Observations of biomass yield characteristics for the first and second ratoon crops revealed that the interaction between fertilizer treatment and genotype did not significantly affect any biomass yield traits. Additionally, the fertilizer treatment alone had no significant impact on all biomass yield traits for the first and second ratoon crops. This suggests that the application of additional nitrogen (N) fertilizer after pruning was sufficient to support the vegetative growth phase of ratoon crops. Plant vegetative growth, including traits such as plant height, number of leaves, and stem diameter, is strongly influenced by nitrogen availability, as N plays a critical role in promoting vegetative development. This finding is consistent with Patti et al. (2013), who reported that N is an essential macronutrient in plant growth, particularly in enhancing vegetative development.

Genotype, however, significantly affected all observed ratoon biomass yield traits. Observations of fresh and dry biomass weight in the first ratoon crops indicated that the NS2-109 genotype had the highest fresh biomass yield (495.83 g) and dry biomass weight (111.03 g). In contrast, the IPB 4 genotype had the lowest fresh biomass (306.98 g) and dry biomass yields (68.91 g). In the second ratoon crops, the NS2-19 genotype produced the highest fresh biomass yield (797.88 g), while the IPB 8 genotype recorded the lowest fresh biomass (568.68 g). The NS2-19 genotype consistently outperformed the others in terms of fresh biomass yield. As for the dry biomass weight in the second ratoon, the NS2-109 genotype again exhibited the highest yield at 151.67 g, whereas the IPB 4 genotype had the lowest dry biomass yield, with 102.20 g. These results demonstrate that the

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NS2-109 genotype was superior in dry biomass yield across both ratoons.

The fresh biomass weight of sorghum is strongly influenced by key agronomic characteristics such as plant height, number of leaves, and stem diameter. The greater the vegetative growth observed, the higher the fresh and dry biomass weights produced. This relationship is confirmed by the correlation coefficient values of the ratoon crops, which are presented in Tables 9 and 10. The correlation coefficient values for the first and second ratoon crops show that plant height, number of leaves, and stem diameter are significantly and positively correlated with the fresh and dry biomass weights in the first ratoon crops. Similarly, Meliala et al. (2017) highlighted that increased plant height and number of leaves result in higher fresh and dry stem weights, supporting the current findings. This suggests that sorghum biomass productivity is closely linked to these agronomic traits, with improved vegetative growth translating into greater biomass yields.

Correlation and Path Analysis of Main and Ratoon Crops

Correlation analysis was performed to assess the strength of the relationship between the observed traits in this study. This analysis provides valuable insights into how specific traits influence biomass yield in the main plant, the first and second ratoon. The relationships between these traits are presented in Table 8 (main crop), Table 9 (first ratoon), and Table 10 (second ratoon).

The correlation coefficient values in the main crop (Table 8), first ratoon (Table 9), and second ratoon (Table 10) revealed that plant height, number of leaves, and stem diameter were significantly and positively correlated with the fresh and dry biomass weights of the first and second ratoon crops. These positive and highly correlated results indicate that as plant height, number of leaves, and stem diameter increase, there is a corresponding increase in biomass yield. This finding aligns with the research of Meliala et al. (2017), which also reported a positive and significant correlation between plant height and stem diameter with wet and dry stalk weights of sorghum plants. Similarly, Abubakar et al. (2013) suggested that traits such as plant height, leaf length, and the number of leaves were positively correlated with increases in sorghum biomass yield.

The correlation results for the second ratoon (Table 10) showed that the number of growing ratoons was negatively correlated with plant height, stem diameter, and fresh weight of biomass. This suggests that an increase in tillers decreases plant height, stem

Table 7. Fresh and dry biomass weights of the main and ratoon crops

Treatment	Fresh biomass weight (g)			Dry biomass weight (g)		
	Main crop	Ratoon 1	Ratoon 2	Main crop	Ratoon 1	Ratoon 2
Fertilizer (F)						
NPK	-	399.18	652.50	-	89.66	131.11
N	-	432.14	713.13	-	93.02	134.87
P- value	-	0.102	0.090	-	0.542	0.594
Genotypes (G)						
NS2-19	469.67	400.25abc	797.88a	102.56ab	81.54ab	141.15ab
NS2-102	480.58	477.47a	732.53ab	108.05ab	106.60a	149.84a
NS2-109	494.50	495.83ab	781.90ab	102.79ab	111.03a	151.67a
NS2-111	472.23	408.82abc	627.87ab	112.52ab	92.09ab	141.21ab
NS2-140	534.43	452.50ab	681.85ab	124.90a	95.86ab	116.27ab
IPB 4	398.20	306.98c	608.58ab	89.16b	68.91b	102.20ab
IPB 8	425.17	324.25bc	568.68b	100.20ab	78.47ab	117.44b
“Numbu”	468.25	459.17ab	663.22ab	107.86ab	96.23ab	144.12ab
P-value	0.163	0.002	0.023	0.049	0.010	0.009
F x G	-	0.597	0.157	-	0.522	0.092
CV (%)	17.05	4.89^{T}	22.37	15.75	5.27^{T}	22.61

Notes: CV = coefficient of variance; ^{T} the square root transformation. Values followed by the same letter in the same column indicate results that are not significantly different based on the HSD test at α < 0.01 (**) and < 0.05 (*).

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diameter, and fresh biomass yield. This is because competition for nutrient absorption intensifies as the number of ratoons increases. This competition reduces the availability of nutrients for each ratoon, resulting in suboptimal growth. Purwati et al. (2023) similarly reported that plant height, number of leaves, stem diameter, and dry stalk weight decrease when the number of ratoons is allowed to proliferate, as creates competition for nutrients.

The path analysis results in Figure 1 illustrate the contribution of vegetative traits and plant physiology to the fresh biomass weight of the main crop. The plant height growth rate (3.32) had the most significant direct effect on the fresh biomass weight of the main plant, followed by stem diameter (0.21). These path analyses are based on the previous correlation results, which showed that plant height and stem diameter were positively and significantly correlated with the fresh biomass weight of the second ratoon plant. This indicates that greater plant height and stem diameter produce a higher fresh biomass weight for the first ratoon plant.

The path analysis results in Figure 2 illustrate the contribution of vegetative traits and plant physiology to the fresh biomass weight of the second ratoon crops. Plant height of the first ratoon (0.39) had the most significant direct effect on the fresh biomass weight of the ratoon crops, followed by stem diameter (0.33). These path analysis values are derived from the previous correlation results, which showed that plant height and stem diameter growth rates were positively and significantly correlated with the fresh biomass weight of the main crop. This indicates that the greater plant height and stem diameter growth rates, the higher the fresh biomass yield of the main crop.

Similarly, the path analysis results in Figure 3 reveal the contribution of vegetative traits and plant physiology to the fresh biomass weight of the second ratoon crops. The stem diameter of the second ratoon (0.66) had the most significant direct effect on fresh biomass weight, followed by plant height (0.44). This demonstrates that larger stem diameters and greater plant heights produce higher fresh biomass yields in ratoon crops. Furthermore, based on previous correlation results, stem diameter and plant height were positively and significantly correlated with the fresh biomass weight of the second ratoon crops.

Table 8. Correlation between observation characters in the main crop

	GR NL	GR PH	PH	NL	SD	LG	BL	FBW
GR PH	0.235							
PH	0.221	0.998**						
NL	0.741**	0.336*	0.322*					
SD	0.261	-0.010	-0.016	0.418**				
LG	0.048	0.680**	0.661**	0.298*	-0.051			
BL	-0.049	0.596**	0.587**	0.273	0.019	0.589**		
FBW	0.405**	0.792**	0.774**	0.506**	0.250	0.606**	0.412**	
DBW	0.432**	0.733**	0.720**	0.506**	0.304*	0.527**	0.464**	0.829**

Notes: GR= Growth rate, PH= plant height, NL= number of leaves, SD= stem diameter, DBW= dry biomass weight, FBW= fresh biomass weight, LG= leaf greenness, BL= Brix level.

Table 9. Correlation between observation characters in the first ratoon crop

	NRG	PH	NL	SD	FBW	DBW	LG
PH	0.38**						
NL	0.425**	0.512**					
SD	0.305*	0.595**	0.738**				
FBW	0.301*	0.682**	0.654**	0.718**			
DBW	0.195	0.528**	0.541**	0.525**	0.839**		
LG	-0.097	-0.204	-0.064	0.05	-0.06	0.097	
BL	-0.058	-0.086	-0.01	-0.104	-0.048	0.153	0.157

Notes: NRG= number of ratoons grown, PH= plant height, NL= number of leaves, SD= stem diameter, DBW= dry biomass weight, FBW= fresh biomass weight, LG= leaf greenness, BL= Brix level.

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Table 10. Correlation between observation characters in the second ratoon crop

	NRG	PH	NL	SD	FBW	DBW	LG
PH	-0.604**						
NL	-0.307	0.628**					
SD	-0.655**	0.541**	0.548**				
FBW	-0.350*	0.584**	0.507**	0.659**			
DBW	-0.125	0.575**	0.534**	0.353*	0.612**		
LG	0.058	0.171	0.172	-0.012	0.162	0.105	
BL	-0.148	0.392**	-0.043	0.136	0.316	0.475**	0.094

Notes: NRG= number of ratoons grows, PH= plant heigh, NL= number of leaves, SD= stem diameter, DBW= dry biomass weight, FBW= fresh biomass weight, LG= leaf greenness, BL= Brix level

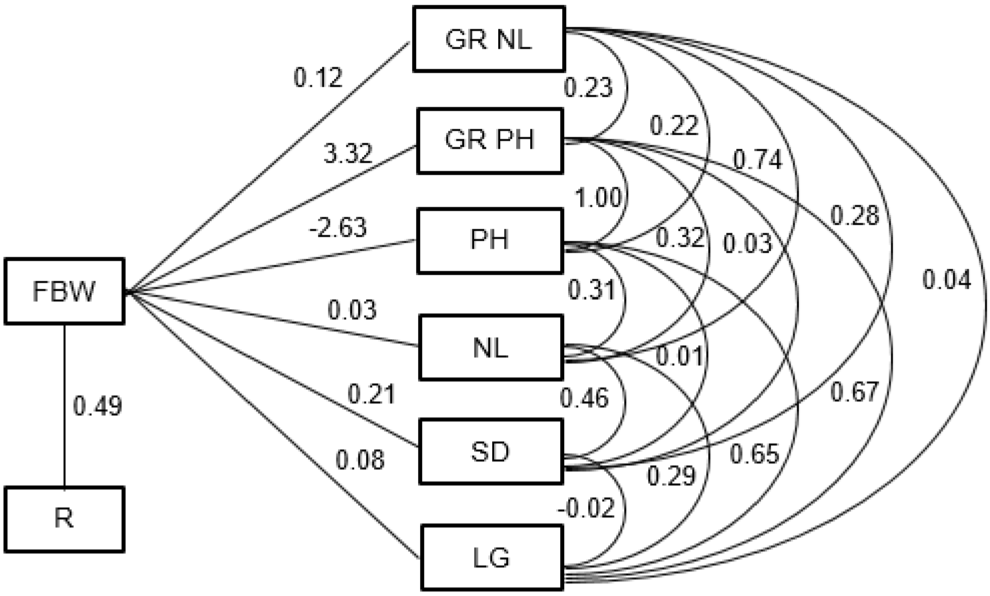

Figure 1. Direct and indirect effects of vegetative characters of the main crop on fresh biomass weight. FBW = fresh biomass weight; GR = growth rate; PH = plant height; NL = number of leaves; SD = stem diameter; LG = leaf greenness.

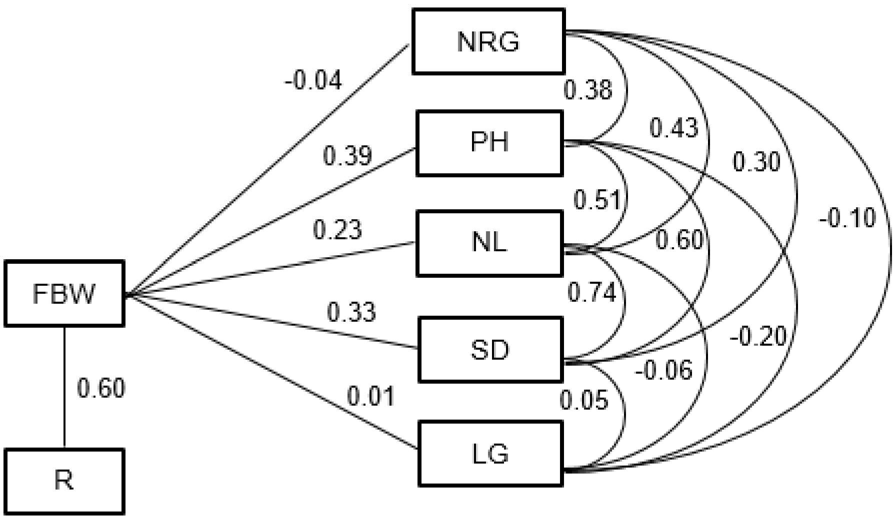

Figure 2. Direct and indirect effects of vegetative characters of first ratoon crops on fresh biomass weight. FBW = fresh biomass weight; NRG = number of ratoons grows; PH = plant height; NH = number of leaves; SD = stem diameter; LG = leaf greenness.

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Comparison of Fresh Biomass Yield of The Main Crop, First Ratoon, and Second Ratoon

There is a significant difference in yield between the main crop and the first and second ratoon crops. As illustrated in Figure 4, the yield of the second ratoon is greater than that of the main plant and the first ratoon. This substantial difference in yield is likely attributable to rainfall variations, as the main crop and the first ratoon are cultivated during the dry season, while the second ratoon is grown during the rainy season. The climatic conditions during the growing seasons for the main crop, first ratoon, and second ratoon are detailed in Table 1.

The main crop was cultivated from June to September, the first from September to October, and the second from October to December. Cultivation of the main crop and the first ratoon occurred during the dry season, with total rainfall measured as 425.0 mm per month in June, 202.5 mm per month in July, 199.0 mm/month in August, and 37.5 mm/month in September for the main crop. The first ratoon experienced 37.5 mm per month in September and 139 mm per month in October. In contrast, the second ratoon was cultivated during the rainy season, with a total rainfall of 1063.5 mm per month in November and 392 mm/month in December (Table 1). This seasonal difference in cultivation resulted in markedly higher biomass production for the second ratoon compared to the main crop and the first ratoon. The relatively high rainfall during the second ratoon cultivation fulfilled the water requirements for optimal plant growth, thereby not disrupting the growth process. Cui et al. (2021) suggested that optimal water availability during the plant growth phase significantly enhances biomass yield. In contrast, drought conditions lead to a loss in biomass weight. Ensuring adequate water availability during cultivation is crucial for achieving high plant biomass yields.

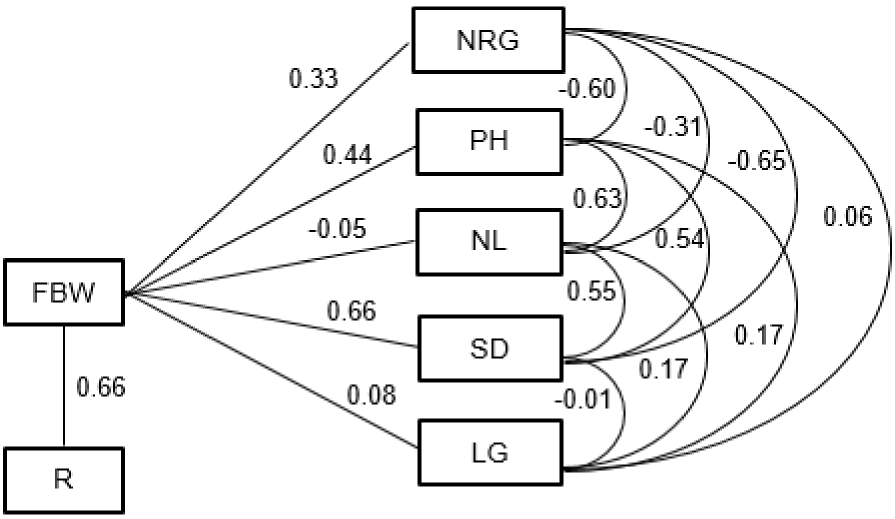

Figure 3. Direct and indirect effects of the vegetative characters of second ratoon crops on fresh biomass weight. FBW = fresh biomass weight; NRG = number of ratoons grows; PH = plant height; NL = number of leaves; SD = stem diameter; LG = leaf greenness.

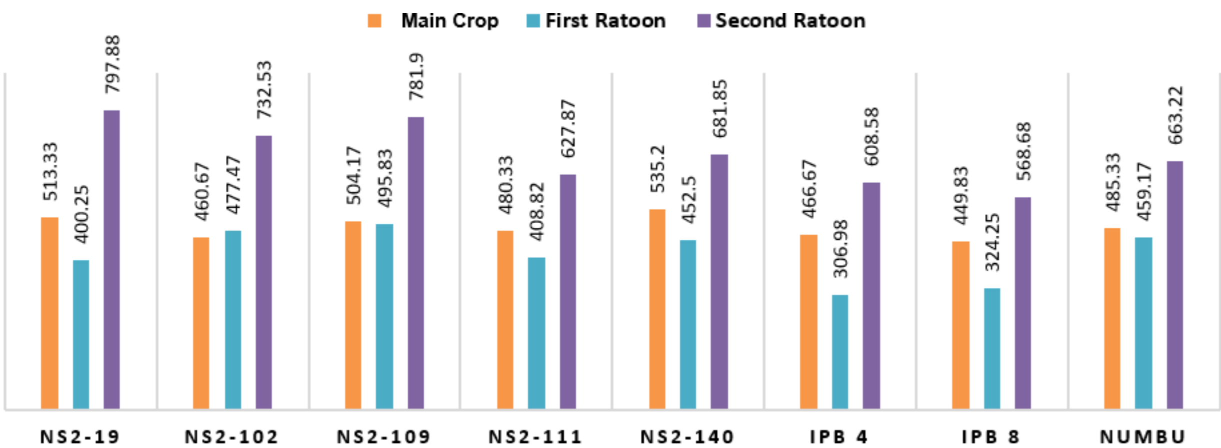

Figure 4. Comparison of sorghum biomass yields of the main crop, the first ratoon, and the second ratoon.

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Low rainfall during the cultivation of the main crop and the first ratoon resulted in stunted plant growth, affecting biomass yield. The limited water availability decreases nutrient availability and nutrient solubility in the soil. As a result, the transport of nutrients from the soil to plant tissues is diminished. This finding is consistent with the research of Hadebe et al. (2020), which indicated that while sorghum can adapt to low water conditions, it experiences reduced plant growth, manifested as fewer green leaves, shorter plant height, decreased canopy cover, and reduced biomass. Similarly, Sharifa et al. (2015) found that drought stress, induced by reduced water application, led to stunted plant growth, reduced plant height, and lower biomass weight.

Conclusion

Plant vegetative growth significantly influences the fresh biomass yield of both main and ratoon crops. Applying N fertilizer on optimal land conditions is effective for sorghum cultivation focused on biomass production. Among the genotypes studied, NS2-140 demonstrated the highest fresh biomass yield in the main plant (534.43 g), NS2-109 yielded the highest fresh biomass yield in the first ratoon (495.83 g), and NS2-19 yielded the highest biomass yield in the second ratoon (797.88 g). Notably, the second ratoon plant exhibited the highest fresh biomass yield of 797.88 g, surpassing the main and first ratoon crops in biomass production.

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