Journal of Agriculture and Environment Vol. 18 No. 2, 2022: 75-90
ISSN: 1595-465X (Print) 2695-236X (Online)

CORRELATED RESPONSE AND PATH ANALYSIS OF SOME GROWTH CHARACTERS TO GRAIN YIELD IN RAINY SEASON SORGHUM (*Sorghum bicolor* (L.) Moench) VARIETIES AT SAMARU AND MAIGANA NORTHERN GUINEA SAVANNAH

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ABSTRACT

Correlation and path analysis was evaluated in 2013 and 2014 wet seasons at the Research Farm of the Institute for Agricultural Research (I.A.R) of Ahmadu Bello University, Zaria, and Kaduna State Agricultural Development Agency, Maigana for seven characters (plant height, number of leaves, leaf area index, crop growth rate, relative growth rate and net assimilation rate). Two sorghum varieties were grown at four rates of cowdung (0, 5, 10 and 15 t ha^{-1}) and inorganic nitrogen (0, 30, 60 and 90 kg N ha^{-1}). Treatments were laid out in a split plot design and replicated three times with nitrogen and cowdung rates assigned in the main plot while varieties were allocated to sub-plots. Grain yield had expressed highly significant and positive correlation with all the parameters in both years, locations and combined except net assimilation rate (0.156), (0.186) at Samaru in 2013 and combined seasons respectively and at Maigana (0.190) in the combined years of the experiment only. The variables that had the strongest positive direct effects on grain yield at Samaru in both years was plant height (0.918), (0.922) except the combined years, where leaf area index (LAI) had the strongest relationship (0.186) while at Maigana number of leaves had the strongest relation (0.746) in 2013 but LAI was the strongest (0.906) and (0.847) in 2014 and combined years respectively. The effects of the other variables were not consistent in both seasons, locations and combined. The highest total percentage contribution to yield at Samaru in 2013 was by LAI (277.15%) while in 2014 and combined seasons was by Plant height (196.21%) and (56.76%) respectively. The highest total percent contribution to yield at Maigana in 2013 was by number of leaves per plant (134.08%) while in 2014 and combined seasons was by plant height (53.56%) and (76.13%) respectively. The interrelationships among these variables might be used in preparing a breeding programme to take advantage of their contributions to yield and develop high yielding sorghum varieties of improved characteristics.

Keywords: Correlation coefficient; path analysis; sorghum varieties; yield

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is extensively cultivated in the tropics, sub-tropics and in other parts of the world as the major staple food grain to many people and feeds to numerous types of livestock. It is adapted to tropical as well as temperate climate, but it is best known for its adaptation to the semi-arid tropics of the world where the areas are drought prone (Kumara*et al*., 2014). The wide adaptability of sorghum to dry conditions as well as its multiple usages gives it great potential to boost the income of small holder farmers in the semi-arid tropics (Rao, 2009).

The crop is considered to be the most important staple food crop in Africa, South Asia and Central America (FAO, 2015). The grain is the principal source of nutrition for many millions of people and provides a major source of protein in human diet in Africa and much of Asia. Besides providing food for humans and feeds for livestock, sorghum stems are used for a wide range of purposes, such as the construction of walls, fences and thatches, fuel as well as production of brooms, mats, baskets, fish- traps and sunshades among others.

In Nigeria, as well as many other countries of the world especially sub-Saharan Africa, apart from its industrial uses, sorghum grain is boiled and consumed like rice or popped like popcorn. The grain is milled into flour and prepared into many local recipes like the thick porridge (*Tuwo*), light porridge (*Akamu*), sorghum composite bread and several other forms of snacks.

The success for breeding and developing a high-quality crop that of sorghum that can tolerate hash environmental conditions depends on identification and analysis of plant traits with sound and positive association that is responsible for best crop performance. For this purpose, the exploitation of correlation and path analysis could be helpful in determining these associations. Correlation coefficients in general, show associations among independent characteristics and the degree of linear relation between these characteristics. It is not sufficient to describe this relationship when the causal association among characteristics is needed (Ali *et al*., 2011). Path analysis is used to know causes. In other words, path analysis is used to determine the amount of direct and indirect effect of the causal components on the affected component (Ramaling *et al*., 2016).

In this study the interrelationship between the grain yield and some growth components of Sorghum were evaluated under rain-fed conditions in 2013 and 2014 seasons at Institute for Agricultural Research (IAR) Samaru, Zaria and Kaduna Agricultural Development Agency, Maigana Zone.

MATERIALS AND METHODS

The Study Area

Field trials were conducted during the 2013 and 2014 rainy seasons at the Institute for Agricultural Research (I.A.R) Farm, Samaru (Latitude 11^0 11’ N, Longitude 09^0 38’ E, at the elevation of 686 m from sea level). and the Kaduna Agricultural Development Agency (KADA) farm at Maigana (Latitude 11^0 39’ N, Longitude 08^0 02’ E, at the elevation of 500 m from sea level). Both experimental sites are in Kaduna State in the northern Guinea savanna ecological zone of Nigeria. The area is characterized by a unimodal rainfall regime that ranges from 1000 – 1500 mm and peaks in the month of August and often terminates in the first or middle of October (Kowal and Knabe, 1972). The vegetation of the area consists of herbaceous grasses, sedges and a low distribution of trees and shrubs of varying proportions. The meteorological information of the area is given in appendices (I & II) and the soil of the experimental site was sandy loam.

The meteorological data of both areas were collected on rainfall, temperatures, relative humidity, and sunshine hour obtained from the Meteorological Units of I.A.R, Samaru and KADA Maigana.

Treatments and Experimental Design

The treatments were laid out in a split plot design and replicated three times with the combinations of nitrogen and cow dung rates assigned in the main plot while the varieties were allocated in the sub-plots. Each sub-plot had a gross size of 6.0 x 4.5 m (144 plants per plot) and a net plot of 6.0 x 1.5 m (48 plants per plot). The rows were spaced at 0.75 m.

The two sorghum varieties (SAMSORG-17 and SAMSORG-44) used were sourced from IAR and were chosen based on their malting characteristics. They have 98 % germination energy which renders them good for malting (Anonymous, 2015).

Variety SAMSORG-17 takes 160 -180 days to mature and attains a height of 1.8 – 2.0 m, its grain colour is yellow and has yield potential range of 2.5 – 3.0 t ha^{-1}.

Variety SAMSORG-44 takes 95 -100 days to mature and attains a height range of 1.6 – 1.8 m, its grain is creamy white and has a potential grain yield range of 2.5 - 3.0 t ha^{-1}.

Cultural Practices

The two varieties were established at 53,000 plants ha^{-1} using the spacing of 0.75 x 0.25 m. sowing was on 30^{th}June, 2013 and 27^{th} July, 2014 at IAR, Samaru and 7^{th} July, 2013 and 3^{rd} July, 2014 at Maigana. The plants were maintained at the factorial combinations of four rates of inorganic nitrogen fertilizers (0, 30, 60 and 90 kg N ha^{-1}) and four rates of cow dung (0, 5, 10 and 15 t ha^{-1}). Urea (46%N) was used to supply N and single superphosphate (SSP,18 % P_2O_5) to supply phosphorus (P) while muriate of potash (MOP, 60 %, K_2O) were used to supply the blanket rates of 32 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1} for all the factorial treatment combinations. The N rates were split applied in two equal doses at sowing and 6 weeks after sowing (WAS).

Data were collected on grain yield and some growth parameters such as plant height, number of leaves $plant^{-1}$, leave area index (LAI), crop growth rate, relative growth rate and net assimilation rate. Simple correlation coefficients were calculated for each pair of growth component parameter using the formula according to Steel and Torries (1984).

$$r = \frac{SP_{xy}}{\sqrt{SSx \times SSy}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where:
r = correlation coefficient between *x* and *y*
SPxy = Sum of product of *x* and *y*
SSx = Sum of squares of *x*
SSy = Sum of squares of *y*

The direct and indirect effects were partitioned by path analysis as described by Wuensch (2016) for 6 independent variables as follows:

$$r1y = P1 + r12P2 + r13P3 + r14P4 + r15P5 + r16P6 \ldots\ldots (2)$$
$$r2y = r12P1 + P2 + r23P3 + r24P4 + r25P5 + r26P6 \ldots\ldots (3)$$
$$r3y = r13P1 + r23P2 + P3 + r34P4 + r35P5 + r36P6 \ldots\ldots (4)$$
$$r4y = r14P1 + r24P2 + r34P3 + P4 + r45P5 + r46P6 \ldots\ldots (5)$$
$$r5y = r15P1 + r25P2 + r35P3 + r45P4 + P5 + r56P6 \ldots\ldots (6)$$
$$ry6 = r16P1 + r26P2 + r36P3 + r46P4 + r56P5 + P6 \ldots\ldots (7)$$

The total percent direct contributions of variables gave the residual effect as given in the equation (8) as follows:
a. The residual effect:

$$(Rx) = 1 - (riP1 + r2yP2 + r3yP3 + r4yP4 + r5yP5 + r6yP6) \ldots\ldots (8)$$

RESULTS

The relationship between grain yield ha^{-1} and growth attributes of two sorghum varieties at Samaru in 2013 are shown in Table 1.

Table 1: Correlation coefficient among some growth attributes of sorghum at Samaru in 2013, 2014 and combined analysis.

2013							
Growth Attributes	1	2	3	4	5	6	7
Grain Yield ha^{-1}	1.000						
Plant height	0.918**	1.000					
Number of leaves $plant^{-1}$	0.899**	0.976**	1.000				
Leaf area index	0.911**	0.972**	0.993**	1.000			
Crop growth rate	0.745**	0.849**	0.877**	0.865**	1.000		
Relative growth rate	0.621**	0.723**	0.690**	0.675**	0.528**	1.000	
Net assimilation rate	0.412**	0.441**	0.506**	0.517**	0.332**	0.261*	1.000
2014							
Growth Attributes							
Grain Yield ha^{-1}	1.000						
Plant height	0.922**	1.000					
Number of leaves $plant^{-1}$	0.846**	0.905**	1.000				
Leaf area index	0.817**	0.928**	0.909**	1.000			
Crop growth rate	0.701**	0.796**	0.878**	0.873**	1.000		
Relative growth rate	0.686**	0.741**	0.867**	0.807**	0.945**	1.000	
Net assimilation rate	0.156	0.334**	0.209	0.271*	0.310*	0.231	1.000
Combined							
Growth Attribute							
Grain Yield ha^{-1}	1.000						
Plant height	0.828**	1.000					
Number of leaves $plant^{-1}$	0.679**	0.50**	1.000				
Leaf area index	0.829**	0.944**	0.575**	1.000			
Crop growth rate	0.680**	0.542**	0.800**	0.678**	1.000		
Relative growth rate	0.561**	0.344**	0.896**	0.442**	0.836**	1.000	
Net assimilation rate	0.186	0.419**	-0.094	0.407**	0.048	-0.165	1.000

* = values above 0.269 Significant at P = 0.05, ** = values above 0.320 highly Significant at P = 0.01

The result showed that grain yield ha^{-1} is highly significantly correlated with plant height (r=0.918**), number of leaves per plant (r=0.899**), leaf area index(r=0.911**), crop growth rate (r=0.745**), relative growth rate (r=0.621**) and net assimilation rate (r=0.412**). Among the highly positive significant correlations, plant height had the strongest relationship (r = 0.918**) with grain yield ha^{-1} while that between net assimilation rate and grain yield ha^{-1} (r = 0.412**) was the weakest.

The relationship between grain yield ha^{-1} and growth attributes of two sorghum varieties at Samaru in 2014 is shown in Table 1. It was observed that grain yield ha^{-1} highly significantly correlated with plant height (r = 0.922), number of leaves per plant (r = 0.846**), leaf area index (r = 0.817**), crop growth rate (r = 0.701**), and relative growth rate (r = 0.686**).

Among the highly positively significant correlations, plant height had the strongest relationship (r = 0.922**) with grain yield ha^{-1} while that between net assimilation rate and grain yield ha^{-} (r = 0.156) was the weakest.

The correlation of grain yield to other growth characters at Samaru combined seasons is shown in Table 1. The result shows that grain yield ha^{-1} significantly and positively correlated with plant height (r = 0.828**), number of leaves per plant (r = 0.679**), leaf area index (r = 0.829**), crop growth rate (r = 0.680**) and relative growth rate (r = 0.561**). Among the highly positively significant correlations, leaf area index had the strongest relationship (r = 0.829**) with grain yield ha^{-1} while that between net assimilation rate and grain yield ha^{-1} (r = 0.186) was the weakest.

The relationship between grain yield ha^{-1} and growth attributes of two sorghum varieties at Maigana in 2013 is shown in Table 2. The result showed that grain yield ha^{-1} highly significantly correlated with plant height (r=0.737**), number of leaves per plant (r=0.746**), leaf area index (r=0.726**), crop growth rate (r=0.661**), relative growth rate (r=0.723**) and net assimilation rate (r=0.555**). Among the highly positively significant correlations, number of leaves per plant had the strongest relationship (r = 0.746**) with grain yield ha^{-1} while that between net assimilation rate and grain yield ha^{-1} (r = 0.555**) was the weakest.

The relationship between grain yield ha^{-1} and growth characters of two sorghum varieties at Maigana in 2014 is shown in Table 2. It was observed that grain yield ha^{-1} highly significantly correlated with plant height (r = 0.889), number of leaves per plant (r = 0.869**), leaf area index (r = 0.906**), crop growth rate (r = 0.813**), relative growth rate (r = 0.839**) and net assimilation rate (r = 0.522**). Among the highly positively significant correlations, leaf area index had the strongest relationship (r = 0.906**) with grain yield ha^{-1} while that between net assimilation rate and grain yield ha^{-1} (r = 0.522**) was the weakest.

The correlation of grain yield to other growth characters at Maigana combined seasons is shown in Table 2. The result shows that grain yield ha^{-1} significantly and positively correlated with plant height (r = 0.792**), number of leaves per plant (r = 0.835**), leaf area index (r = 0.847**), crop growth rate (r = 0.701**), and relative growth rate (r = 827**).

Among the highly positively significant correlations, leaf area index had the strongest relationship (r = 0.847**) with grain yield ha^{-1} while that between the net assimilation rate and grain yield ha^{-1} (r = 0.190) was the weakest and non-significant (p>0.05).

Table 2: Correlation coefficient among some growth attributes of sorghum at Maigana 2013, 2014 and combined analysis

2013							
Growth Attributes	1	2	3	4	5	6	7
Grain Yield ha^{-1}	1.000						
Plant height	0.737**	1.000					
Number of leaves plant^{-1}	0.746**	0.792**	1.000				
Leaf area index	0.726**	0.471**	0.985**	1.000			
Crop growth rate	0.661**	0.821**	0.784**	0.753**	1.000		
Relative growth rate	0.723**	0.642**	0.847**	0.789**	0.835**	1.000	
Net assimilation rate	0.555**	0.574**	0.407**	0.365**	0.667**	0.665**	1.000
2014							
Growth Attributes							
Grain Yield ha^{-1}	1.000						
Plant height	0.889**	1.000					
Number of leaves plant^{-1}	0.869**	0.901**	1.000				
Leaf area index	0.906**	0.731**	0.958**	1.000			
Crop growth rate	0.813**	0.848**	0.854**	0.818**	1.000		
Relative growth rate	0.839**	0.904**	0.931**	0.877**	0.917**	1.000	
Net assimilation rate	0.522**	0.659**	0.612**	0.130	0.788**	0.751**	1.000
Combined							
Growth Attributes							
Grain Yield ha^{-1}	1.000						
Plant height	0.792**	1.000					
Number of leaves plant^{-1}	0.835**	0.738**	1.000				
Leaf area index	0.847**	0.748**	0.261*	1.000			
Crop growth rate	0.701**	0.821**	0.653**	0.641**	1.000		
Relative growth rate	0.827**	0.788**	0.868**	0.839**	0.844**	1.000	
Net assimilation rate	0.190	0.472**	0.067	0.017	0.632**	0.394**	1.000

* = values above 0.269 Significant at P = 0.05, ** = values above 0.320 highly Significant at P = 0.01

A path coefficient analysis was carried out to partition the contributions of each growth character to determine its direct and indirect contributions via other measured characters to the grain yield which otherwise referred to as the total contribution of a growth character to grain yield using the path coefficient analysis in both years and combined.

The direct and indirect effects of the different growth characters on grain yield during the two seasons and the combined seasons at Samaru are shown in Table 3. All the direct effects to grain yield were negative except those from plant height (0.788), and leaf area index (1.066) in 2013, however, positive except for relative growth rate (-0.005) and net assimilation rate (-0.085) in 2014, leaf area index (-0.386), crop growth rate (-0.109) and net assimilation rate (-0.176) in the combined seasons. Likewise, the indirect effects via other yield characters were also negative except the contributions by plant height and leaf area index via all the other characters in 2013, plant height, number of leaves per plant and relative growth rate in 2014, but positive except for relative growth rate and net assimilation rate in the combined seasons.

When the individual percentage (%) contributions of growth characters to grain yield were considered in 2013 (Figure 1) the result shows plant height directly contributing 62.25% to yield while its combined (indirect) contributions with number of leaves per plant, leaf area index, crop growth rate, relative growth rate, and net assimilation rate were -101.55, 161.51 -26.63, -10.55, -4.40% respectively. Number of leaves per plant made a direct contribution of 43.48% to yield, but indirectly in combination with leaf area index, crop growth rate, relative growth rate, and net assimilation rate contributed -139.60, 22.998, 8.42 and 4.22% respectively. The leaf area index contributed113.64 % while indirectly with crop growth rate, relative growth rate, and net assimilation rate contributed -36.66, -13.319 and -6.82% respectively. Crop growth rate directly made a contribution of 3.95% but indirectly with relative growth rate and net assimilation rate contributed 1.94% and 0.84%. Relative growth rate directly contributed 0.85% but indirectly with net assimilation rate contributed 0.31%.

The highest direct contribution to yield was from leaf area index 113.64%in 2013 while the least was from net assimilation rate 0.40%. Similarly, the highest indirect contribution to yield was from plant height 163.51% through leaf area index while the least was from plant height through number of leaves per plant -101.56%. And the highest total percentage contribution to yield was by leaf area index 277.15% from its direct contribution of 113.64% and its indirect contribution with plant height of 163.51%.

The contributions of the various characters to grain yield in 2014 (Figure 2) shows plant height directly contributed 162.44% while its indirect contributions with number of leaves per plant 5.08%, leaf area index -91.40%, crop growth rate -22.25%, relative growth rate 33.77%, net assimilation rate -15.06% respectively.

Number of leaves per plant directly contributed 0.04% but indirectly with leaf area index, crop growth rate, relative growth rate, and net assimilation rate contributed -1.55, -0.42 0.682 and -0.16% respectively. Leaf area index has directly made a contribution of 14.93% while indirectly with crop growth rate, relative growth rate and net assimilation rate contributed 7.39 -11.15 and 2.86%. Crop growth rate directly made a total contribution of 1.20% to yield but indirectly with relative growth rate and net assimilation rate contributed -3.71 and 1.20%. The direct contribution of relative growth rate was 3.19% but its indirect contribution with net assimilation rate was -1.46%.

The highest direct contribution to yield was by plant height162.45% while the least was from number of leaves per plant 0.05%. The highest indirect contribution to yield was by plant height via relative growth rate 33.77%. However, the least was by plant height via leaf area index -91.40%. And the highest total percentage contribution to yield was by plant height196.21% from its direct contribution of 162.44% and its indirect contribution with relative growth rate of 33.77%.

The result of the direct and indirect contributions of the various characters to yield in the combined seasons (Figure 3) shows plant height directly contributing 42.38% but indirectly with number of leaves, leaf area index, crop growth rate, relative growth rate and net assimilation rate 14.37,3.97, 9.39, -0.02 and -4.67%. The direct contribution of number of leaves per plant to yield was 4.883% but indirectly with leaf area index, crop growth rate, relative growth rate and net assimilation rate contributed 0.82, 4.70, -0.02 and 0.35%

respectively. Leaf area index directly contributed 0.10%to yield while indirectly with crop growth rate, relative growth rate and net assimilation rate contributed 0.58, -0.002 and 0.05% respectively. The direct contribution of crop growth rate was 1.77% but indirectly with relative growth rate and net assimilation rate were -0.01 and -0.11%. Relative growth rate directly contributed 2.86% while indirectly with net assimilation rate contributed =0.001%.

The highest direct contribution to yield in the combined years was by plant height 42.38% while the least was by leaf area index0.10% however, the highest indirect contributions was made by plant height with number of leaves per plant14.38% while the least was by plant height with net assimilation rate -4.67%. And the highest total percentage contribution to yield was by plant height (56.76%) from its direct contribution of 42.38% and its indirect contribution with number of leaves per plant 14.38%.

Table 3: The direct and indirect contributions of the different growth components to yield at Samaru in 2013, 2014 and combined

	Direct and Indirect contributions	Effects						
	2013	2	3	4	5	6	7	**Total**
2	Plant height	**0.789**	-0.644	1.036	-0.169	-0.067	-0.028	**0.918**
3	Number of leaves plant^{-1}	0.770	**-0.659**	1.058	-0.174	-0.064	-0.032	**0.899**
4	Leaf area index	0.767	-0.655	**1.066**	-0.172	-0.062	-0.032	**0.911**
5	Crop growth rate	0.669	-0.578	0.922	**-0.199**	-0.049	-0.021	**0.745**
6	Relative growth rate	0.570	-0.455	0.719	-0.104	**-0.092**	-0.016	**0.621**
7	Net assimilation rate	0.348	-0.333	0.551	-0.066	-0.024	**-0.063**	**0.412**
	2014							
2	Plant height	**1.275**	0.019	-0.358	-0.087	0.132	-0.059	**0.922**
3	Number of leaves plant^{-1}	1.153	**0.022**	-0.351	-0.096	0.155	-0.036	**0.846**
4	Leaf area index	1.182	0.020	**-0.386**	-0.096	0.144	-0.048	**0.817**
5	Crop growth rate	1.015	0.019	-0.337	**-0.109**	0.169	-0.055	**0.701**
6	Relative growth rate	0.944	0.019	-0.311	-0.103	**0.179**	-0.041	**0.686**
7	Net assimilation rate	0.426	0.005	-0.105	-0.034	0.041	**-0.177**	**0.156**
	Combined							
2	Plant height	**0.651**	0.110	0.030	0.072	-0.001	-0.036	**0.828**
3	Number of leaves plant^{-1}	0.325	**0.221**	0.019	0.107	-0.004	0.008	**0.679**
4	Leaf area index	0.615	0.127	**0.032**	0.090	-0.002	-0.035	**0.829**
5	Crop growth rate	0.353	0.177	0.022	**0.133**	-0.004	-0.004	**0.68**
6	Relative growth rate	0.224	0.198	0.014	0.111	**-0.005**	0.014	**0.561**
7	Net assimilation rate	0.273	-0.021	0.013	0.006	-0.008	**-0.086**	**0.186**

The direct and indirect effects of the different growth characters on grain yield during the two seasons and the combined seasons at Maigana are shown in Table 4. All the direct effects to grain yield were negative except those from number of leaves per plant (1.013) and net assimilation rate (0.369) in 2013, however, positive except leaf area index (-0.048) and net assimilation rate (-0.325) in 2014, number of leaves (-0.062), leaf area index (-0.048) and net assimilation rate (-0.304) in the combined seasons. The indirect effects via other growth characters were negative except the contributions by number of leaves per plant and net assimilation rate via all the other characters in 2013, but positive except for leaf area index and net assimilation rate in 2014, number of leaves per plant, leaf area index and net assimilation rate in the combined seasons.

The direct and indirect effects of the different growth characters on grain yield during the two seasons and the combined seasons at Maigana are shown in Figure 4. When the direct % contribution of growth characters to grain yield was considerd, plant height directly contributed 0.04% to yield but indirectly with number of leaves per plant, leaf area index, crop growth rate, relative growth rate and net assimilation rate-3.45, 0.52, 0.37, 0.21and -0.91% respectively. The direct contribution of number of leaves per plant to yield was 102.62%, while its indirect contributions with leaf area index, crop growth rate, relative growth and net assimilation rate were -51.45, -16.43, -13.23 and 30.46% respectively. Leaf area index made a direct contribution to yield of 6.65% but indirectly with crop growth rate, relative growth rate and net assimilation rate contributed 4.02, 3.140 and -7.75% respectively. Crop growth rate directly contributed 1.07% to yield while its indirect contributions with relative growth rate and net assimilation rate were 1.33 and -5.09% respectively. Relative growth direct contribution to yield was 0.597% but indirectly with net assimilation rate contributed -3.79%.

The highest direct contribution to yield was by number of leaves per plant 102.62% while the least was from plant height 0.05%. The highest indirect contribution to yield was by number of leaves per plant via net assimilation rate 30.46%. However, the least was by number of leaves per plant via leaf area index -51.45%. And the highest total percentage contribution to yield was by number of leaves per plant 134.08% from its direct contribution of 102.62% and its indirect contribution with net assimilation rate of 30.46%.

When the direct % contribution of growth characters to grain yield was considered in 2014 (Figure 5) it shows that plant height directly contributed 28.61% to yield but indirectly with number of leaves per plant, leaf area index, crop growth rate, relative growth rate and net assimilation rate 24.95 -3.78 37.85, 1.81 and -22.94% respectively. The direct contribution of number of leaves per plant to yield was 6.70%, while its indirect contributions with leaf area index, crop growth rate, relative growth and net assimilation rate were -2.39, 18.45, 0.90 and -10.31% respectively. Leaf area index made a direct contribution to yield of 0.23% but indirectly with crop growth rate, relative growth rate and net assimilation rate contributed -3.30, -0.16 and 1.93% respectively. Crop growth rate directly contributed to yield 17.41% while its indirect contributions with relative growth rate 1.43% and net assimilation were1.43 and-21.39% respectively. Relative growth rate direct contribution to yield was 0.04% but indirectly with net assimilation rate contributed -0.92%.

The highest direct contribution to yield was by plant height28.61% while the least was from relative growth rate 0.04%. The highest indirect contribution to yield was by plant height via crop growth rate 37.35%. However, the least was by plant height via net assimilation rate -22.94 %. And the highest total percentage contribution to yield was by plant height 53.56% from its direct contribution of 28.61% and its indirect contribution with number of leaves per plant of 24.95%.

Table 4. The direct and indirect contributions of the different growth components to yield at Maigana.

	Direct and Indirect contributions	Effects						
	2013	2	3	4	5	6	7	Total
2	Plant height	**-0.021**	0.802	-0.121	-0.085	-0.049	0.212	**0.737**
3	Number of leaves plant^{-1}	-0.017	**1.013**	-0.254	-0.081	-0.065	0.150	**0.746**
4	Leaf area index	-0.010	0.998	**-0.258**	-0.077	-0.060	0.135	**0.726**
5	Crop growth rate	-0.017	0.794	-0.194	**-0.103**	-0.064	0.246	**0.661**
6	Relative growth rate	-0.014	0.858	-0.203	-0.086	**-0.077**	0.246	**0.723**
7	Net assimilation rate	-0.012	0.412	-0.094	-0.069	-0.051	**0.369**	**0.555**
	2014							
2	Plant height	**0.535**	0.233	-0.035	0.353	0.017	-0.214	**0.889**
3	Number of leaves plant^{-1}	0.482	**0.259**	-0.046	0.356	0.017	-0.199	**0.869**
4	Leaf area index	0.391	0.248	**-0.048**	0.341	0.016	-0.042	**0.906**
5	Crop growth rate	0.454	0.221	-0.039	**0.417**	0.017	-0.256	**0.813**
6	Relative growth rate	0.484	0.241	-0.042	0.383	**0.017**	-0.244	**0.839**
7	Net assimilation rate	0.352	0.158	-0.006	0.329	0.014	**-0.325**	**0.522**
	Combined							
2	Plant height	**0.511**	-0.046	-0.037	0.018	0.489	-0.144	**0.792**
3	Number of leaves plant^{-1}	0.377	**-0.062**	-0.013	0.014	0.539	-0.020	**0.835**
4	Leaf area index	0.382	-0.016	**-0.049**	0.014	0.521	-0.005	**0.847**
5	Crop growth rate	0.419	-0.041	-0.031	**0.022**	0.524	-0.193	**0.701**
6	Relative growth rate	0.403	-0.054	-0.041	0.019	**0.621**	-0.120	**0.827**
7	Net assimilation rate	0.241	-0.004	-0.008	0.014	0.245	**-0.305**	**0.19**

The result of the direct and indirect contributions of the various characters to yield in the combined seasons (Figure 6) shows plant height contributing 26.12% but indirectly with number of leaves, leaf area index, crop growth rate, relative growth rate and net assimilation rate contributing -4.70, -3.74, 1.85, 50.01 and -14.71%. The direct contribution of number of leaves per plant to yield was 0.39%but indirectly with leaf area index, crop growth rate, relative growth rate and net assimilation rate contributed 0.16, -1.18, -6.72 and 0.25% respectively. The leaf area index directly contributed 0.24% to yield while with crop growth rate, relative growth rate, and net assimilation rate contributed -0.14, -5.09 and 0.19% respectively. The direct contribution of crop growth rate was 0.05% but indirectly with relative growth rate and net assimilation rate were 2.31 and -0.85%. Relative growth rate directly contributed 38.5% while indirectly with net assimilation rate contributed -14.91%.

The highest direct contribution to yield in the combined seasons was by relative growth rate 38.55% while the least was by crop growth rate 0.05% similarly, the highest indirect contributions was made by plant height via relative growth rate of 50.01% while the least was by plant height with net assimilation rate -14.71%. And the highest total percentage contribution to yield was by plant height of 76.13% from its direct contribution of 26.12% and its indirect contribution with relative growth rate of 50.01%.

Figure 1= Path diagram relating the grain yield of sorghum to some growth components at Samaru in 2013

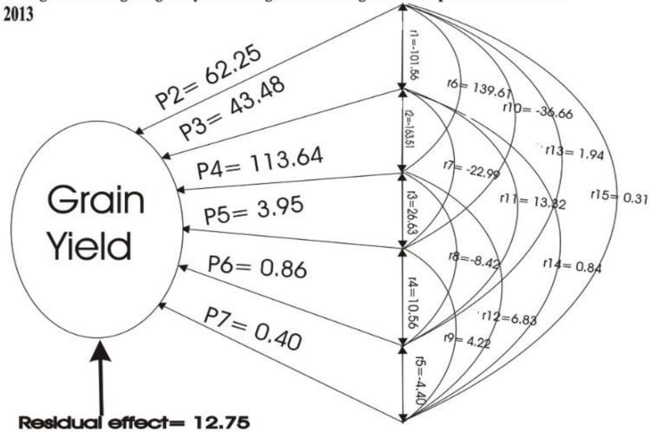


Figure 2= Path diagram relating the grain yield of sorghum to some growth components at Samaru in 2014

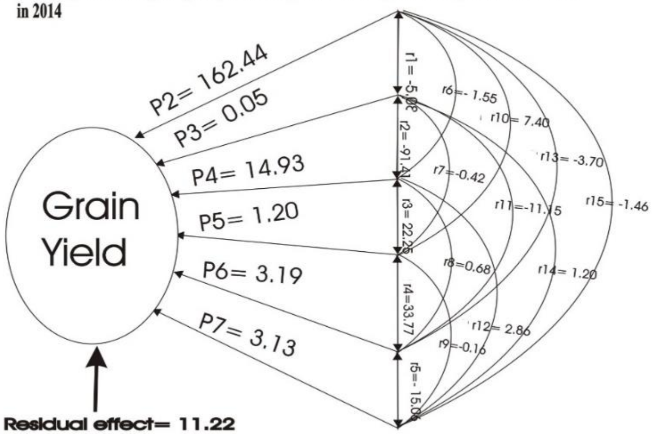
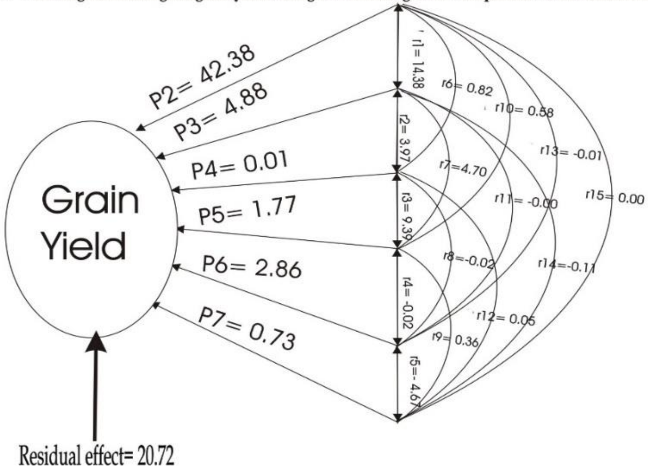


Figure 1= Path diagram relating the grain yield of sorghum to some growth components at Samaru combined



KEYS

P2 ...... P7 = Individual direct percent contributions of some growth and yield characters to sorghum grain yield

Where P2= Plant height (cm)
P3= Number of leaves per plant
P4= Leaf Area Index
P5= Crop Growth Rate
P6= Relative Growth Rate
P7= Net Assimilation Rate

r1 ... . R r15= indirect percent combined contributions of some growth and yield Characters to sorghum grain yield via P2 ......P7

Figure 4= Path diagram relating the grain yield of sorghum to some growth components at Maigana in 2013

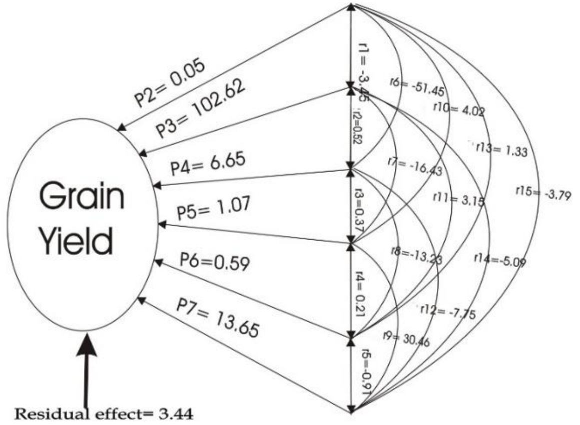


Figure 5= Path diagram relating the grain yield of sorghum to some growth components at Maigana in 2014

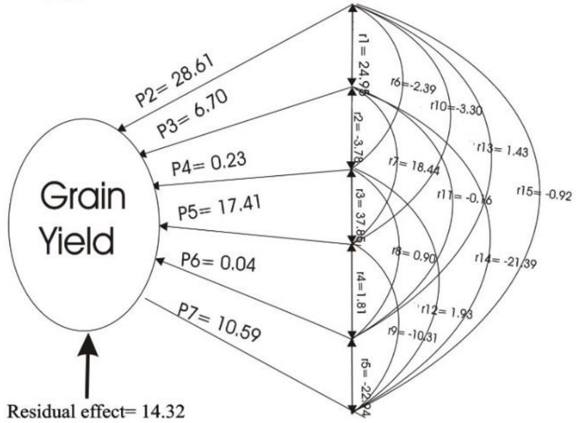
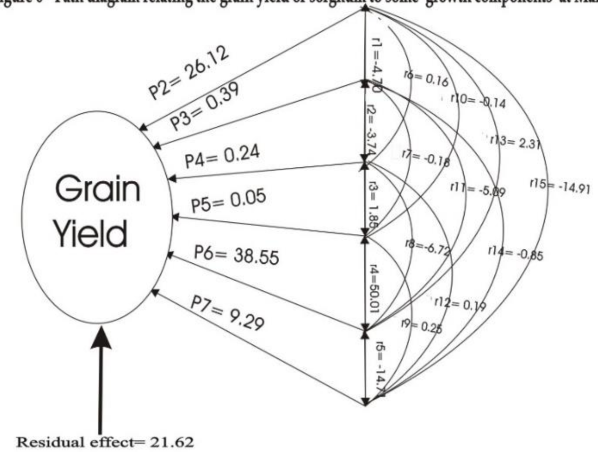


Figure 6= Path diagram relating the grain yield of sorghum to some growth components at Maigana combined



KEYS

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Where P2= Plant height (cm)
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P7= Net Assimilation Rate

r1 ... . R r15= indirect percent combined contributions of some growth and yield Characters to sorghum grain yield via P2 ......P7

DISCUSSION

The significant and positive relationship exhibited between grain yield ha^{-1} and plant height, number of leaves per plant, leaf area index, crop growth rate, relative growth rate and net assimilation rate at locations, years and combined seasons confirmed the interdependence and the yield contributing nature of these plant parameters. It can therefore be further explained that taller plants, a greater number of leaves and larger leaf area index are required for better interception of light for high assimilate production which eventually transmitted into grain formation. A taller plant with a greater number of leaves and larger assimilatory area connotes high tendencies of more light interception by a crop. Parameters such as number of leaves, LAI determine the photosynthetic surface area for interception of adequate sunlight for the production of assimilates and thus higher dry matter partitioning to the grains which constitute yield. This finding corroborates the earlier reports by Goma (2011) and Abunyewa *et al*. (2009) who observed significant and positive relationship between plant height, number of leaves per plant and grain yield of sorghum. The direct and indirect effects of plant height, number of leaves per plant, crop growth rate, relative growth rate and net assimilation rate as some of the primary determinants for yield may be attributed to the influence of the complementary application of organic and inorganic fertilizer rates, which improved crop growth and eventually lead to more assimilates production and partitioning for high grain filling that contributed to yield.

The path coefficient analysis at both locations, years and combined seasons revealed that the highest direct contribution among the growth characters was not consistent among the locations, years and combined seasons. At Samaru, the highest direct contribution was from LAI in 2013 while at Maigana, it was number of leaves per plant that made the highest contribution to yield. The highest indirect contribution to yield was by number of leaves per plant with LAI at Samaru. Similarly, at Maigana, it was LAI with number of leaves per plant. Plant height made the highest direct contribution to yield in 2014 at both locations. However, the indirect contributions of relative growth rate and LAI with plant height made the highest contributions at Samaru and Maigana respectively. The combined seasons result reveals that at Samaru, the direct contributions of plant height and the indirect contributions of LAI with plant height were the highest. However, at Maigana, the direct contributions of relative growth rate and the indirect contributions of crop growth rate with plant height were the highest. The highest direct and indirect contributions to yield observed by the various yield characters suggest that these characters have the efficiency for production and partitioning of assimilate into yield being the most important apparatus responsible for assimilating production and partitioning that eventually translated into economic yield of sorghum. These findings corroborated with the earlier reports of Goma *et al*. (2020).

CONCLUSION

This study has demonstrated that plant height, number of leaves per plant, leaf area index, crop growth rate, relative growth rate and net assimilation rate are among the most important determinant of sorghum yield. The highest percentage total direct and indirect contributions to yield was by the growth parameters such as plant height, number of leaves per plant, LAI and relative growth rate. These findings suggest that these parameters have the efficiency for production of assimilate and partitioning into yield being the most important apparatus responsible for assimilating production and translocation that eventually translated into economic yield of sorghum. Therefore, they should be considered when planning a technology that is aiming at improving sorghum yield.

Acknowledgements

The authors wish to sincerely acknowledge the management of the Institute for Agricultural Research, Ahmadu Bello University, Zaria for their support in providing the research field, land preparation and logistics. Our gratitude also goes to the Department of Agronomy, Faculty of Agriculture, A.B.U, Zaria for providing the technical staff who assisted in data and samples collections during the two-season experiment.

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Appendix I: Meteorological data showing monthly rainfall, temperature, relative humidity and Sunshine hours at Samaru during 2013 and 214 seasons

Months	Rainfall (mm)		Temperatures (^{0}C)				Relative Humidity (%)				Sunshine Hours	
			Minimum		Maximum							
	2013	2014	2013	2014	2013	2014	10:00a.m*	4:00p.m	10:00a.m	4:00p.m	2013	2014
January	0.0	0.4	32.5	33.4	17.7	17.2	21.7	17.8	18.6	12.7	8.0	8.7
February	0.0	0.0	35.5	34.3	18	19.0	14.9	12.1	15.4	12.4	7.4	8.2
March	0.0	0.0	39.3	38.0	22.8	22.1	38.1	14.6	26.7	19.4	7.6	7.4
April	73.8	141.7	37.5	36.9	24.0	24.0	52.9	24.8	54.3	39.9	7.0	7.1
May	66.5	127.2	35.4	33.4	24.8	24.2	64.6	50.9	67.3	51.0	7.7	6.3
June	167	119.1	31.0	32.0	13.0	21.1	69.6	60.0	72.9	61.0	6.7	7.2
July	314.9	115.7	30.8	31.4	20.0	20.1	80.0	67.6	78.0	70.0	6.3	6.3
August	163	374.3	30.3	30.0	19.6	20.2	83.0	72.7	82.0	72.8	7.1	5.3
September	233	180.2	32.0	31.0	18.9	21.0	77.0	65.6	77.8	70.0	6.2	5.8
October	10.6	9.3	34.1	33.9	18.2	19.1	54.0	41.8	61.0	41.0	7.8	8.1
November	0.0	0.0	34.2	30.0	15.9	14.0	24.5	18.6	27.0	20.0	9.2	8.8
December	0.0	0.0	29.0	26.2	11.9	13.2	19.0	13.6	19.6	13.9	8.8	8.4
Total	1028.8	1067.8	-	-	-	-	-	-	-	-	-	-
TRGC	721.5	798.6	-	-	-	-	-	-	-	-	-	-

Source: Metrological Unit of Institute for Agricultural Research (IAR) Samaru, Zaria
Key: TRGC = Total Rainfall during the Growth of the Crop.
* = 10:00 a.m and 4:00 p.m are 09:00 and 15:00 GMT, respectively.

Appendix II: Meteorological data showing monthly rainfall, temperature, relative humidity and Sunshine hours at Maigana during 2013 and 2014 seasons

Month	Rainfall (mm)		Temperatures				Relative Humidity (%)			
			Minimum		Maximum		2013		2014	
	2013	2014	2013	2014	2013	2014	10:00a.m*	4:00p.m	10:00a.m	4:00p.m
January	0.0	0.0	33.0	33.0	18.0	17.3	20.5	16.3	15.9	10.7
February	0.0	0.0	36.2	35.0	18.7	20.0	14.9	13.3	13.5	10.9
March	0.0	0.0	39.6	38.3	23.3	23.2	36.9	14.5	24.7	19.0
April	70.3	124.7	38.0	37.1	24.5	23.7	51.0	23.6	53.0	37.5
May	59.7	110.5	35.8	34.2	25.0	24.1	62.7	48.9	65.1	50.0
June	126.0	115.0	33.2	32.4	23.1	23.0	65.3	56.0	71.7	67.9
July	144.3	125.0	31.6	32.0	24.0	24.3	77.0	63.3	74.0	68.0
August	228.0	285.0	30.0	29.7	22.7	23.0	80.0	70.4	80.0	70.3
September	90.5	163.0	31.5	30.9	23.4	21.3	71.0	61.6	75.3	68.0
October	4.7	6.2	33.9	33.5	20.5	21.0	50.5	39.7	60.0	39.0
November	0.0	0.0	35.8	35.7	17.0	15.7	22.0	16.3	25.0	18.0
December	0.0	0.0	34.1	33.8	16.7	14.5	15.0	11.9	17.0	12.9
Total	723.5	923.4	-	-	-	-	-	-	-	-
TRGC	593.5	694.2	-	-	-	-	-	-	-	-

Source: Metrological Units of Kaduna Agricultural Development Project (KADP)

Key: TRGC = Total rainfall during the Growth of the Crop.

* = 10:00 a.m and 4:00 p.m are 09:00 and 15:00 GMT, respectively.

n.a = Not available