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SOURCE-SINK RELATIONSHIP IN HAUSA POTATO

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ABSTRACT

Fresh tuber yield of Hausa potato [*Solenostemon rotundifolius* (Poir) J.K. Morton] is generally low in Nigeria, perhaps, due to a lack of balance between the source and the sink. The objective of this study was to investigate the relationship between source-potential and sink-capacity, and its effect on dry matter production and distribution, as well as on dry tuberous yield in reciprocal grafts of four accessions of Hausa potato. Four accessions of Hausa potato were used for reciprocal grafting. The degree of response of source to sink and of sink to source was determined using regression coefficient analysis. The number of tubers per plant, length and girth of tubers varied with accession, source-potential and sink-capacity. The highest source-potential was observed in accession Manchok 2. The highest sink-capacity was observed in accession Langtang. Although accession Manchok 2 had the largest source-potential with respect to dry tuber yield, the highest response of source to sink was observed in accession Bokkos 2, with regression coefficient of 0.83. Accession Langtang had the highest sink-capacity, but the degree of response of sink to source was highest in accession Bokkos 2 with regression coefficient of 3.26. The results showed that the photosynthetic capacity of accessions with large source-potentials is unlikely to be altered by change in sink-capacity. Productivity in Hausa potato may be influenced by the photosynthetic activity of the leaf canopy (source), the capacity of the plant to translocate photo-assimilates to the tuberous root (sink) and the capacity of the tuberous root to accommodate or capture the assimilates.

Key Words: *Solenostemon rotundifolius,* sink capacity, source potential

RÉSUMÉ

Rendement de tubercules frais de pomme de terre haoussa [*Solenostemon rotundifolius* (Poir) J.K. Morton] est généralement faible au Nigéria, peut-être en raison d'un manque d'équilibre entre la source et le puits. L'objectif de cette étude était d'étudier la relation entre le potentiel source et la capacité de puits, et son effet sur la production et la distribution de matière sèche, ainsi que sur le rendement tubéreux sec dans les greffes réciproques de quatre accessions de pomme de terre Haoussa. Quatre accessions de pomme de terre Haoussa ont été utilisées pour le greffage réciproque. Le degré de réponse de la source au puits et du puits à la source a été déterminé à l'aide d'une analyse des coefficients de régression. Le nombre de tubercules par plante, la longueur et la circonférence des tubercules variaient selon l'accession, le potentiel de la source et la capacité du puits. Le potentiel de source le plus élevé a été observé dans l'accession Manchok 2. La capacité de puits la plus élevée a été observée dans l'accession Langtang. Bien que l'accession Manchok 2 ait le plus grand potentiel de source en ce qui concerne le rendement en tubercules secs, la réponse la plus élevée de la source au puits a été observée dans l'accession Bokkos 2, avec un coefficient de régression de 0,83. L'accession Langtang avait la capacité de puits la plus élevée, mais le degré de réponse du puits à la source était le plus élevé dans l'accession Bokkos 2 avec un coefficient de régression de 3,26. Les résultats ont montré qu'il est peu probable que la capacité photosynthétique des accessions à fort potentiel de source soit altérée par une modification de la capacité de puits. La productivité de la pomme de terre Haoussa peut être influencée par l'activité photosynthétique de la canopée foliaire (source), la capacité de la plante à transloquer les photo-assimilats vers la racine tubéreuse (puits) et la capacité de la racine tubéreuse à accueillir ou à capturer les assimilats.

Mots Clés : *Solenostemon rotundifolius*, capacité de puits, potentiel de source

INTRODUCTION

Hausa potato (*Solenostemon rotundifolius* [Poir) J.K. Morton] is listed among the orphan crops in most parts of Africa. It is one of the most widespread of the cultivated Lamiaceae with economic importance (Blench and Dendo, 2004; Nkansah, 2004; PROTA, 2013). It is characterised by a distinctive fragrant or pungent odour, resulting from volatile oils contained in glands or sacs found in the leaves and other parts (NRC, 2006). Even though it produces many flowers, few seeds are produced. Therefore, it is usually propagated by whole tubers or soft, woody stem-cuttings (Nkansah, 2004).

Hausa potato is a tasty and nutritious tuber crop, with a high carbohydrate content of up to 83.5% of dry matter weight (Gouado *et al.*, 2003). It is rich in protein, calcium, magnesium, fiber and iron, when compared with cassava, yam and sweet potato (Gouado *et al.*, 2003; Prematilake, 2005). It has medicinal properties due to the presence of flavonoids, which help to lower cholesterol in the blood (Horvath *et al.*, 2004; Abraham and Radhakrishnan, 2005).

The physiological basis of dry matter production in crop plants is influenced by the relationship between the source and the sink. The source is the potential capacity for photosynthesis, while the sink is the potential capacity to store or effectively use the photosynthates. The size and activities of both source and sink affect yield (Alam *et al.*, 2008; Shekoofa and Eman, 2008). Some plant parts act as sources; some are both sources and sinks; while others are always sinks (Alam *et al.*, 2008; Shekoofa and Eman, 2008).

The understanding of the relationship between the source-potential and the sink-capacity can be used to improve yield in crop plants. It is important to determine which of the two, source or sink, limits yield (Namo, 2016). In other words, yield is affected not only by the production of dry matter, but also by the way it is distributed to different parts of the plant. A low sink capacity can result in assimilate accumulation in the source, thereby lowering the photosynthetic activity. Similarly, a low source-potential can result in a low production of assimilate that should be made available to the tubers (Foyer and Mathew, 2001). The objective of this study was to investigate the relationship between the source-potential and sink-capacity and its effect on dry matter production and distribution as well as on dry tuberous yield in reciprocal grafts of four accessions of Hausa potato in Jos-Plateau, Nigeria.

MATERIALS AND METHODS

The experiment was conducted between the months of April and October, 2018 at the Federal College of Forestry Jos, Plateau State, Nigeria. The College is located at an altitude of 1,159 m above sea level on latitude 09^{0} 30‘E and longitude 08^{o} 20‘N.

The four accessions of Hausa potato used in this study were sourced from the following locations as presented in Table 1. These were selected based on the results of a previous study (Namo and Opaleye, 2018). Eighty sprouted tubers of the accessions were planted in black polyethylene bags filled with top soil, manure and river sand in a potting ratio of 3:2:1, respectively (Namo, 2016). The agronomic characteristics of accessions used in the study are shown in Table 2.

Eight weeks after planting, when all the sprouted tubers had emerged, reciprocal grafts of the four accessions were made in all possible combinations, including four self-grafts (Namo, 2016). For each graft-combination in each accession, four (4) grafts were made, giving a total of 64 grafts. The cleft grafting technique was used. A scion with 4 or 5 fully developed leaves was pruned and grafted onto the rootstock. The grafted portion was wrapped with a grafting tape to prevent it from drying. It was thereafter covered with a white polyethylene bag to provide heat for the grafted portion and to ensure the successful union of the grafts (Namo, 2016).

Two weeks after the graft union had been established, successful grafts were counted and recorded. The pots were manually weeded as the need arose. Cow dung manure was applied 4 weeks after grafting. The grafts were pruned regularly to remove any sprout from the stock or tuber from the scion, so that only the scion was allowed to produce leaves which served as the main photosynthetic organs; while the stock served as the non-photosynthetic organ, that is, for tuber formation (Namo, 2016). Figure 1 shows the procedure and technique used in the grafting.

Field observations and data collection commenced at 45 days after grafting (45

TABLE 1. Sources of accessions used in the study

Accession no.	Name	Source
Accession 1	NRCRI (White)	National Root Crops Research Institute (NRCRI), Kuru, Jos
Accession 2	Bokkos 2	Bokkos, Plateau State
Accession 3	Manchok 2	Manchok, Kaduna State
Accession 4	Langtang	Langtang, Plateau State

TABLE 2. Agronomic characteristics of the accessions used in the study

Accession	No. of branches per plant	Leaf area index	Dry matter content	Harvest index	Total tuber yield (t ha^{1})
NRCRI (White)	17.00	0.44	27.00	0.76	3.83
Bokkos 2	15.63	0.25	21.84	0.76	1.42
Manchok 2	28.75	0.22	23.24	0.70	1.42
Langtang	6.50	0.29	25.87	0.63	0.10

Source: Namo and Opaleye (2018)

(a) (b)

(c) (d)

Figure 1. Procedure and technique used in the grafting of Hausa potato. (a). Hausa potato plant grown at 8 weeks after planting, (b). Prepared rootstock of Hausa potato, (c). A scion grafted on the rootstock, and (d). A graft union of Hausa potato at 4 weeks after grafting.

DAG) and ended at 120 DAG. One plant was sampled from each plot for the growth analysis study at 45 and 90 DAG. Each harvested plant was washed using distilled water and separated into roots, stems and leaves. All the plant parts were placed in separate envelopes and dried in moisture-extraction oven at 80 ^{O}C for 48 hours to obtain constant weight.

Leaf area index was measured using the leaf-disc method (Namo, 2016); which involves the removal of leaves from the sampled plant from each plot, determination of the total dry weight and of the area/weight relationship of a sub-sample taken from the mass of leaves with a punch of a known diameter. The cross-sectional area of the punch used in this study was 0.3 cm^2.

Fifty discs were taken from each sample and placed in brown envelopes for drying to constant weight in a moisture-extraction oven at 80 ^{O}C for 48 hours. The rest of the leaves, along with the remains of the punched leaves, were put into separate envelopes and dried at the same temperature and time. Leaf area index was then calculated as the ratio of total leaf area to the land area occupied by the sampled plant (Gregory, 1918; Namo, 2016).

$$\text{Leaf area} = \frac{\text{Area of 1 disc x No of discs x Total leaf dry weight}}{\text{Dry weight of discs}}$$

.... Equation 1

$$\text{Leaf area index} = \frac{\text{Leaf area}}{\text{Land area occupied by sampled plant}}$$

.... Equation 2

Net assimilation rate was calculated from the data obtained on dry weight of plants using the method of Gregory (1918) as cited by Namo (2016).

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{Loge\ L_2 - LogeL_1}{L_2 - L_1}$$

.... Equation 3

Where:

W_1 and W_2 are total dry weights of harvested plant parts at times t_1 and t_2, respectively.
L_1 and L_2 are the leaf area at times t_1 and t_2, respectively.
Log_e is the natural logarithm.

The length and girth of two tubers sampled from each plot were measured, using a measuring tape. The number of tubers harvested in each pot at harvest was recorded as the number of tubers per plant.

The sink capacity of each accession was measured as the mean stock effect on the dry tuberous yield when it was grafted with each of the other accessions as the scion. The source potential of each accession was measured as the mean scion effect on the dry tuberous yield when it was grafted with each of the other accessions as the sink (Namo, 2016).

The regression of a scion on the mean stock effects on dry tuberous root yield when it was grafted on a set of accessions as stock measured the degree of response of source to sink (Dahniya, 1979; Hahn, 1982; Namo, 2016). In other words, it estimated the relative advantage of changing the size of the source to produce more dry matter which could be captured by a large sink for increased fresh tuber yield. The regression of a stock on the mean scion effects on dry tuberous root yield when it was grafted with a set of accessions as scion measured the degree of response of sink to source, that is, it estimated the advantage of changing the size of the sink to accommodate the large quantity of photo-assimilates produced by the source so that fresh tuber yield could be increased (Dahniya, 1979; Hahn, 1982; Namo, 2016). The values of both the source-potential and sink-capacity were plotted on the X-axis; while values of dry tuberous yield of self-grafts were plotted on the Y-axis, in order to estimate the balance between the source and the sink (Dahniya, 1979; Namo, 2016).

Data collected were subjected to one-way analysis of variance test, using the Statistical Analysis Software (SAS, version 9.0). Means were compared using the least significant difference at 5% level of probability.

RESULTS

Leaf area index. Generally, leaf area index increased with time in all, but the self-graft of accession Langtang; as well as grafts NRCRI (White) x Bokkos 2 and NRCRI (White) x Langtang (Table 3).

Net assimilation rate. At 45 days after grafting (45 DAG), the lowest NAR of 0.07 ± 0.19 $gm^{-2}\ week^{-1}$ was observed in the grafts Bokkos 2 x Manchok 2 and NRCRI (White) x Manchok 2; the highest NAR value of 2.36 ± 0.19 $gm^{-2}\ week^{-1}$ was observed in the graft Bokkos 2 x NRCRI (White). At 90 DAG, the lowest NAR of 0.01± 0.19 $gm^{-2}\ week^{-1}$ was observed in the self-graft of accession Langtang, while the highest (0.46 ± 0.19 $gm^{-2}\ week^{-1}$) was observed in the graft Bokkos

TABLE 3. Leaf area index and net assimilation rate (NAR) (gm^{-2} week^{-1}) (x10^{-3}) of reciprocal grafts of four accessions of Hausa potato at different stages of growth in Jos, Nigeria

Graft combination		LAI		NAR	
		Growth stage		Days after grafting	
Stock	Scion	45	90	45	90
Bokkos 2	Bokkos 2	0.99	1.71	0.63	0.05
Bokkos 2	NRCRI (White)	0.22	0.54	2.36	0.46
Bokkos 2	Langtang	0.63	1.06	0.42	0.15
Bokkos 2	Manchok 2	0.25	0.46	0.07	0.15
Langtang	Langtang	0.47	0.29	0.12	0.01
Langtang	NRCRI (White)	0.14	1.16	0.20	0.05
Langtang	Bokkos 2	0.20	0.73	0.21	0.06
Langtang	Manchok 2	0.17	0.56	0.56	0.12
Manchok 2	Manchok 2	0.18	0.64	0.18	0.13
Manchok 2	NRCRI (White)	0.21	0.24	0.39	0.03
Manchok 2	Bokkos 2	0.11	0.11	2.15	0.35
Manchok 2	Langtang	1.16	1.63	0.40	0.12
NRCRI (White)	NRCRI (White)	0.14	0.43	1.97	0.04
NRCRI (White)	Bokkos 2	1.29	0.77	0.67	0.02
NRCRI (White)	Langtang	0.51	0.17	0.14	0.03
NRCRI (White)	Manchok 2	0.58	0.74	0.07	0.21
SED		0.16		0.19	

SED = Standard error of difference

2 x NRCRI (White). Generally, the NAR decreased with time in all, but the grafts Bokkos 2 x Manchok 2 and NRCRI (White) x Manchok 2 (Table 3).

Number of tubers per plant. Although the number of tubers per plant varied from 3.5 in the self-graft of Langtang to 11.0 in grafts Bokkos 2 x Manchok 2 and NRCRI (White) x Langtang, the differences (P>0.05) were not significant (Table 4). The highest mean stock effect (sink capacity) of 9.9 was observed in accession NRCRI (White); while the lowest (5.9) was observed in accession Langtang. The mean scion effect (source potential) varied from 6.1 in accession NRCRI (White) to 10.0 in accession Manchok 2 (Table 4).

Tuber length. The greatest mean tuber length of 5.8 cm was observed in the graft Langtang x Bokkos 2; while the lowest (2.9 cm) was observed in the graft Bokkos 2 x NRCRI (White) (Table 5). The highest mean stock effect of 4.83 cm was observed in accession NRCRI (White); while the lowest (3.87 cm) was observed in accession Bokkos 2 (Table 5). The mean scion effect varied from 3.26 cm in accession NRCRI (White) to 4.72 cm in accessions Bokkos 2 and Langtang (Table 5).

Tuber girth. The highest mean tuber girth of 9.0 cm was observed when accession NRCRI (White) as stock was combined with accession Manchok 2 as scion. The

TABLE 4. Number of tubers per plant of reciprocal grafts of four accessions of Hausa potato at harvest

Stock	Scion				
	BOKKOS 2	LANGTANG	MANCHOK 2	NRCRI (White)	Mean stock (sink) effect
BOKKOS 2	10.15[a]	9.00[a]	11.00[a]	7.00[a]	9.38[a]
LANGTANG	7.50[a]	3.50[a]	8.50[a]	4.00[a]	5.88[a]
MANCHOK 2	9.50[a]	9.50[a]	10.00[a]	6.00[a]	8.75[a]
NRCRI(White)	10.50[a]	11.00[a]	10.50[a]	7.50[a]	9.88[a]
SED			4.77		
Mean scion(source) effect	9.50[a]	8.25[a]	10.00[a]	6.13[a]	
SED (Mean effect)			2.05		

Figures underlined are for self-grafts

TABLE 5. Mean tuber length (cm) of reciprocal grafts of four accessions of Hausa potato grown in Jos in 2018

Stock	Scion				
	BOKKOS 2	LANGTANG	MANCHOK 2	NRCRI (White)	Mean stock (sink) effect
BOKKOS 2	3.85[b]	4.35[a]	4.35[a]	2.93[c]	3.87[b]
LANGTANG	5.80[a]	4.60[a]	4.35[a]	3.45[b]	4.55[a]
MANCHOK 2	3.40[b]	5.68[ab]	3.58[b]	3.40[b]	4.02[ab]
NRCRI (White)	5.83[a]	4.25[a]	6.00[a]	3.25[b]	4.83[a]
SED			0.95		
Mean scion (source) effect	4.72[a]	4.72[a]	4.57[a]	3.26[b]	
SED (Mean effect)			0.31		

Figures underlined are for self-grafts

combination of accession Bokkos 2 as stock with NRCRI (White) as scion resulted in the lowest mean tuber girth of 3.6 cm (Table 6). The mean stock effect varied from 5.44 cm in accession Bokkos 2 to 6.37 cm in accession NRCRI (White). The highest mean scion effect of 6.91 cm was observed in accession Manchok 2; while the lowest (4.91 cm) was observed in accession NRCRI (White).

Dry tuberous yield. The highest dry tuberous root yield of 20.83 g plant^{-1} was observed in the graft Langtang x Bokkos 2; followed by NRCRI (White) x Manchok 2 (19.25 g

TABLE 6. Mean tuber girth (cm) of reciprocal grafts of four accessions of Hausa potato grown in 2018

Stock	Scion				
	BOKKOS 2	LANGTANG	MANCHOK 2	NRCRI (White)	Mean stock (sink) effect
BOKKOS 2	$\underline{6.48}^{b}$	5.15^{b}	6.50^{b}	3.63^{c}	5.44^{a}
LANGTANG	7.55^{a}	$\underline{4.83}^{b}$	6.85^{b}	5.58^{b}	6.20^{a}
MANCHOK 2	4.83^{b}	7.30^{a}	$\underline{5.28}^{b}$	4.98^{b}	5.60^{a}
NRCRI (White)	6.55^{b}	4.50^{b}	9.00^{a}	$\underline{5.43}^{b}$	6.37^{a}
SED			1.55		
Mean scion (source) effect	6.35^{ab}	5.45^{bc}	6.91^{a}	4.91^{c}	
SED (Mean effect)			0.56		

Figures underlined are for self-grafts

plant^{-1}), Bokkos 2 x Manchok 2 (17.18 g plant^{-1}), Langtang x Manchok 2 (16.12 g plant^{-1}) and Manchok 2 x Manchok 2 (14.16 g plant^{-1}). The lowest dry tuberous root yield of 7.76 g plant^{-1} was observed in the self-graft of accession Langtang (Table 7). The mean stock effect varied from 12.26 g plant^{-1} in accession Bokkos 2 to 15.88 g plant^{-1} in accession Langtang. The highest mean scion effect of 16.68 g plant^{-1} was observed in accession Manchok 2, and this was followed by accessions Bokkos 2 (13.08 g plant^{-1}), NRCRI (White) (10.96 g plant^{-1}) and Langtang (10.61 g plant^{-1}).

Table 8 shows dry tuberous root yield of the four accessions of Hausa potato, which were planted without grafting to serve as the control. The dry tuberous root yield varied from 17.56 g plant^{-1} in accession Bokkos 2 to 33.79 g plant^{-1} in accession Manchok 2; the differences ($P>0.05$) were, however, not significant. The dry tuberous root yields of the non-grafts were generally higher than the mean stock effects of the respective accessions.

Response of sink to source and of source to sink. The bj and bi values were computed as shown in Table 7. The b_j values (response of sink to source) were plotted against the respective sink capacities (Fig. 2). Although accession Langtang showed a large sink capacity, accession Bokkos 2 showed the highest response of sink to source with a regression coefficient of 3.26. This was followed by accession NRCRI (White). Accession Langtang showed the lowest response of sink to source with a regression coefficient of 0.26 (Table 7). The b_i values, which measured the degree of response of source to sink, were plotted against the respective source potentials (Fig. 3). Although accession Manchok 2 had the highest source potential with respect to dry tuberous root yield (16.68 g plant^{-1}), accession Bokkos 2 showed the highest response of source to sink, with a regression coefficient of 0.83, and was followed by accession Langtang (0.81) and Manchok 2 (0.29). Accession NRCRI (White) showed the least response of source to sink with a regression coefficient of 0.28 (Table 7).

TABLE 7. Dry tuberous root yield (g/plant) of reciprocal grafts' of four accessions of Hausa potato grown in Jos

Stock	Scion					
	BOKKOS 2	LANGTANG	MANCHOK 2	NRCRI	Mean stock (White) (sink) effect	b_1
BOKKOS 2	<u>8.31[b]</u>	10.56[a]	17.18[a]	12.97[a]	12.26[a]	3.26
LANGTANG	20.83[a]	<u>7.76[b]</u>	16.12[a]	10.80[a]	15.88[a]	0.26
MANCHOK 2	10.03[a]	13.67[a]	<u>14.16[a]</u>	9.08[b]	13.48[a]	0.34
NRCRI(White)	13.16[a]	10.43[a]	19.25[a]	<u>10.97[a]</u>	13.45[a]	1.07
SED			6.42			
Mean scion (source) effect	13.08[ab]	10.61[b]	16.68[a]	10.96[b]		
SED (Mean effect)			2.10			
b_i	0.83	0.81	0.29	0.28		

Figures underlined are for self-grafts

TABLE 8. Dry tuberous root yield (g plant^{-1}) of non-grafts of four accessions of Hausa potato grown in Jos

Accession	Dry tuberous root yield (g plant^{-1})
BOKKOS 2	17.56[a]
LANGTANG	23.44[a]
MANCHOK 2	33.79[a]
NRCRI White	24.26[a]
$LSD_{0.05}$	24.01

Means followed by the same letter(s) are not significantly different at 5% level of probability

Relation between source potential and sink capacity on dry tuberous yield of self-grafts. The dry tuberous root yields of the self-grafts were plotted against the respective source potentials (mean scion effects) and sink capacities (mean stock effects). Figure 4 shows that accession Langtang had a low dry tuberous root yield and that the source potential and sink capacity of this accession were different. Accessions Bokkos 2 and NRCRI (White) had medium dry tuberous root yields; however, whereas the source potential and sink capacity of Bokkos 2 were not quite different, those of accession NRCRI (White) were very different. Accession Manchok 2 had the highest dry tuberous root yield with a different source potential and sink capacity (Fig. 4).

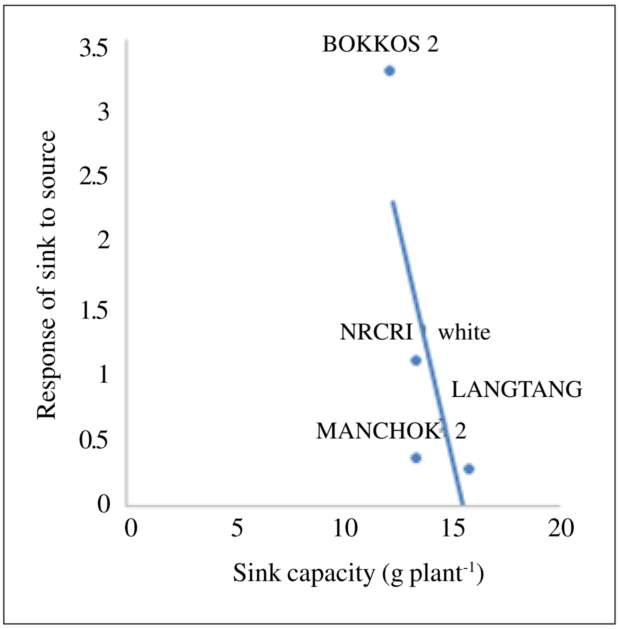

Figure 2. Response of sink to source in four accessions of Hausa potato.

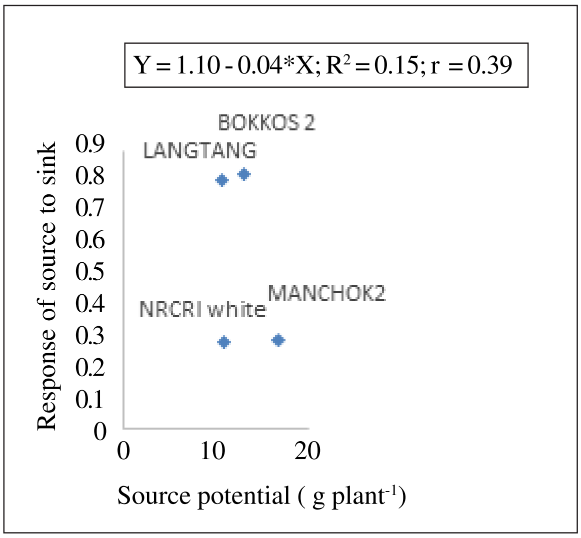

Figure 3. Response of source to sink in four accessions of Hausa potato.

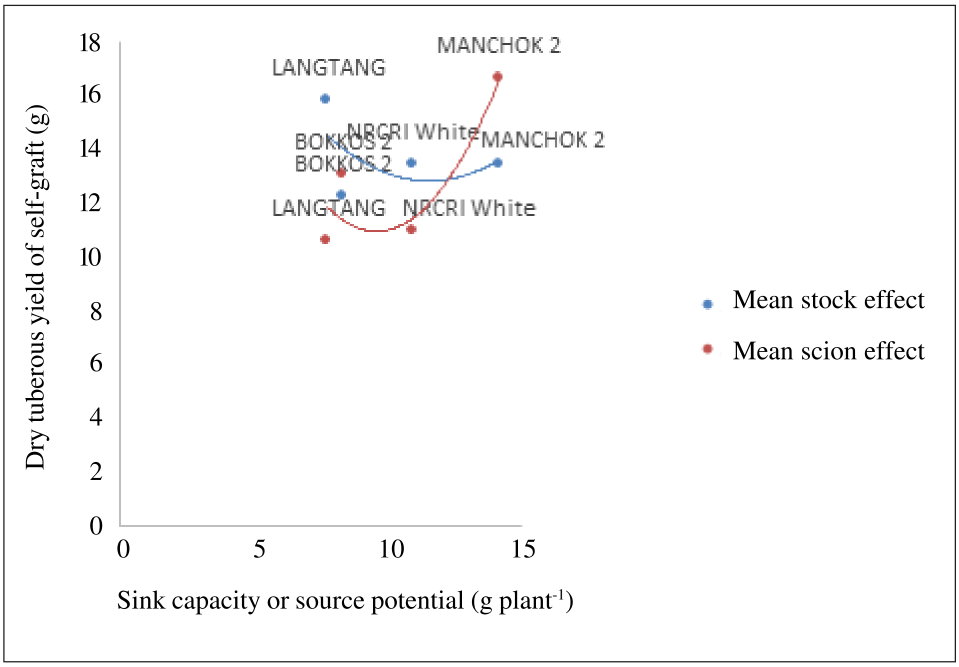

Figure 4. Relation between source potential and sink capacity on dry tuberous yield of self-grafts of four accessions of Hausa potato.

DISCUSSION

Leaf area index. The leaf area index increased with time up to 90 days after grafting (DAG) in almost all the grafts (Table 3). Leaf area index could not be assessed beyond 90 days after grafting due to the low rate of establishment of grafts. Generally, in root and tuber crops leaf area and leaf area index increased due to the production of new leaves in the early stages of growth. However, as the cropping season progressed, leaf area and leaf area index decreased due to senescence of old leaves and the decrease in the formation of new leaves. Mature leaves represented a loss in the photosynthetic capacity of the plant. Archana *et al.* (2017) reported increases in the leaf area index in the early stages of growth, which thereafter declined slowly up to the time of harvest under subtropical condition. Namo (2016) reported increase in leaf area index of reciprocal grafts of sweet potato up to 90 days after grafting in the mid-altitude highland environment of the Jos-Plateau in Nigeria.

Net assimilation rate. The net assimilation rate generally decreased from 45 days after grafting (45 DAG) in almost all the grafts (Table 3). As the cropping season progresses, light interception improves and the rate of dry matter production increases. However, due to mutual shading, photosynthesis no longer exceeds respiration in older leaves, which then cease to be net producers of dry matter (Namo, 2016).

Number of tubers per plant, tuber length and tuber girth. The mean number of tubers per plant varied from 3.5 in the self-graft of accession Langtang to 11.0 in grafts NRCRI (White) x Langtang and Bokkos 2 x Manchok 2 (Table 4). Like the number of tubers per plant, the mean tuber length and tuber girth varied with accession and graft-combination (Tables 5 and 6). The highest mean stock effect on tuber length and tuber girth was observed in accession NRCRI (White); while the lowest was observed in accession Bokkos 2. The wide variation in length and girth of tubers in this study indicated that the sink (tubers) still had a large potential capacity to take in assimilates. The results suggest that the assimilates supplied by the source were not sufficient enough to meet the demands of the sink-growth, an observation, which has also been reported for the potato by Li *et al.* (2016). The results also show that fresh tuber yield in Hausa potato is dependent not only on tuber number, but on tuber size, which in turn may be influenced by the source-potential, sink-capacity or the rate of translocation of assimilates from the source to the sink (Namo, 2016).

Dry tuberous root yield. The dry tuberous root yield varied from 8.3 g per plant in the self-graft of Bokkos 2 to 20.8 g per plant in the graft Langtang x Bokkos 2. The mean scion effect was highest in accession Manchok 2 and lowest in accession Langtang (Table 7). The dry tuberous root yields of the non-grafts were generally higher than the mean stock effects of the respective accessions (Table 8). The dry tuberous root yield of Hausa potato, like other tuberous root crops, depends on the photosynthetic activity of the leaf canopy, the rate of translocation of assimilates from the leaves (source) to the tuberous root (sink) and the capacity of the tuberous root to capture the assimilates. This supply must be controlled in some way if a balance of parts is to be maintained; limitations of any of these factors may affect yield (Forbes and Watson, 1992; Namo, 2016). Dahniya (1979) reported the development of large tubers by cassava, which he suggested were due to the fact that these organs are strong sinks which accumulate high proportions of total photosynthetic products. Enyi (1977) noted that the proportion of assimilate translocated to the tubers depended on competition for supplies by other parts. Although a positive relation between source-potential and sink-capacity was reported in the sweet potato (Enyi, 1977), the trend in this study was different. Unlike the sweet potato, the period of production of new leaves (leaf area duration) in Hausa potato is relatively longer, resulting in competition for assimilates between the photosynthetic leaves (source) and the tubers (sink). Golovko and Tabalenkova (2019) reported that in the potato the leaves of the middle layers had the greatest area, exported ^{14}C directly to the tubers, and spent 40% of assimilated carbon on their own needs. The competition for photo-assimilates between newly produced leaves and the growing tubers in Hausa potato appears to be in favour of the leaves, resulting in the generally low fresh tuber yield.

Although the highest mean stock effect (sink-capacity) of 15.88 g per plant was observed in accession Langtang, the highest dry tuberous root yield of 20.83 g per plant was observed when accession Langtang as stock was combined with accession Bokkos 2 as scion. Similarly, although the highest scion effect (source-potential) of 16.68 g per plant was observed in accession Manchok 2, the highest dry tuberous root yield of 20.83 g per plant was observed when accession Langtang as stock was grafted to accession Bokkos 2 as scion. The interaction of stock and scion on the dry tuberous root yield in this study shows that source and sink sizes can easily be exchanged through reciprocal grafting in order to increase yield. The results also indicate that fresh tuber yield in Hausa potato is dependent not only on the source-potential or sink-capacity, but on, among others, the balance between the two. Namo (2016) reported a similar observation in the sweet potato grafts grown in the Jos-Plateau environment in Nigeria. These findings provide the basis for understanding the methods that govern the source-sink relationship in Hausa potato in an effort to improve its productivity.

Although accession Langtang showed a large sink capacity of 15.5 g per plant, accession Bokkos 2, with a regression coefficient of 3.26, demonstrated the highest response of sink to source (Table 7). Similarly, even though accession Manchok 2 showed the highest source-potential of 16.7 g per plant, accession Bokkos 2 had the highest response of source to sink with respect to the dry tuberous root yield. These results indicate that accessions with high source potentials or large sink capacities do not necessarily demonstrate the highest response of source to sink or of sink to source. This means that the photosynthetic capacity of an accession with a high source-potential is unlikely to be altered by merely changing the sink capacity. Similar findings have been reported by Li and Kao (1990) and Namo (2016). However, Hahn (1977) observed that a variety of sweet potato with poor sink capacity showed a low response of sink to source even though a good source was provided. He concluded that sink was the primary factor affecting high tuber yield while source was secondary.

The dry tuberous root yields of the self-grafts were plotted against the source-potentials (mean stock effects) and sink capacities (mean stock effects). Figure 4 shows that accession Bokkos 2 had a low dry tuberous root yield and that the source potential and sink capacity of accession were not quite different. This was closely followed by accession Langtang with a source-potential and a sink-capacity that were different. Accession NRCRI (White) had a medium dry tuberous root yield with different source-potential and sink-capacity. Accession Manchok 2 with the highest dry tuberous root yield had a source-potential and a sink capacity that were also different. The results show that the source-potentials and sink-capacities of the four accessions of Hausa potato used in this study are not balanced.

CONCLUSION

This study has demonstrated that the dry tuberous root yield in Hausa potato could be affected by the source potential, sink capacity and, perhaps, the rate of translocation of assimilates from the source to the sink. Accession Bokkos 2 showed the highest response of sink to source, even though accession Langtang had the largest sink capacity. Similarly, whereas accession Manchok 2 had the highest source potential with respect to dry tuberous root yield, accession Bokkos 2 showed the highest response of source to sink. It was envisaged that exchanging the source-potentials and sink-capacities of these accessions would have improved the tuber yield of the grafted plants when compared with those that were planted without grafting. That this was not evident shows that factors other than the size and activities of the source and sink could be responsible for productivity of Hausa potato. Therefore, there is the need for further investigation.

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