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Competition Indices of Forage Sorghum (*Sorghum almum*) Intercropped with Lablab (*Lablab purpureus)* in the Northern Guinea Savanna of Nigeria

***[1]Ishiaku, Y. M., [1] Hassan, M. R. [2]Salisu S.G. and [3]M.A. Haruna**

[1]*Feeds and Nutrition Research Programme, National Animal Production Research Institute, Ahmadu Bello University, Zaria.*

[2]*Department of Animal Science, Ahmadu Bello University, Zaria.*

[3]*Division of Agricultural Colleges, Samaru College of Agriculture, Ahmadu Bello University, Zaria*

***Corresponding author:** ishiaku.ym2014@gmail.com: +2348101055090

Abstract

*The overreliance on monoculture systems and the escalating cost of livestock feed in Nigeria necessitate the adoption of sustainable agricultural practices such as intercropping. Understanding the competitive dynamics between component crops is crucial for optimizing these systems. This study was conducted to evaluate the competition indices and economic profitability of intercropping forage sorghum (*Sorghum almum*) with lablab (*Lablab purpureus*) in the Northern Guinea Savanna of Nigeria. A field study was conducted during the 2017 and 2018 rainy seasons. The experiment was laid out in a Randomized Complete Block Design with a 5 x 4 factorial arrangement, replicated three times. The factors consisted of five planting patterns (4:0, 3:1, 2:2, 1:3, and 0:4 rows of* S. almum *to* L. purpureus*) and four lablab intercropping days (0, 7, 14, and 21 days after sowing DAS forage sorghum). Key competition indices calculated included Land Equivalent Ratio (LER), Competitive Ratio (CR), Aggressivity (A), Relative Crowding Coefficient (K), Actual Yield Loss (AYL), and Monetary Advantage Index (MAI). Intercropping consistently demonstrated a significant yield advantage over sole cropping, with mean total LER values greater than unity across all patterns (1.79 - 1.83). The 3:1 planting pattern and simultaneous sowing (0 DAS) produced the highest LER (1.83 and 1.96, respectively), indicating land use efficiency gains of 83-96%. Forage sorghum was the dominant competitor, exhibiting higher CR and positive A values, while lablab was subordinate. The Relative Crowding Coefficient was highest in the 2:2 pattern. Despite some indications of yield loss per plant (negative partial AYL), the system was economically profitable. The highest Monetary Advantage Index (MAI = 412.39) was obtained from the 3:1 planting pattern, confirming its economic superiority. Intercropping* Sorghum almum *with* Lablab purpureus *is agronomically beneficial and economically viable in the Northern Guinea Savanna. For optimal productivity and profitability, it is recommended that farmers adopt a 3:1 row ratio and intercrop lablab simultaneously (0 DAS) with forage sorghum. This practice enhances land use efficiency and provides a sustainable strategy for improving forage production for smallholder crop-livestock systems.*

Keywords: *Sorghum almum*; *Lablab purpureus*; intercropping; competition indices; monetary advantage

Indices de Compétition du Sorgho Fourrager (*Sorghum almum*) en Association avec le Lablab (*Lablab purpureus*) dans la Savane Guinéenne Nord du Nigéria

Résumé

La dépendance excessive aux systèmes de monoculture et le coût croissant des aliments pour le bétail au Nigéria rendent nécessaire l'adoption de pratiques agricoles durables telles que l'association de cultures. La compréhension de la dynamique de compétition entre les cultures associées est cruciale pour optimiser ces systèmes. Cette étude a été menée pour évaluer les indices de compétition et la rentabilité économique de l'association du sorgho fourrager (Sorghum almum) avec le lablab (Lablab purpureus) dans la Savane

Guinéenne Nord du Nigéria. Une étude en plein champ a été conduite pendant les saisons des pluies 2017 et 2018. L'expérience a été mise en place selon un dispositif en blocs complets randomisés avec un arrangement factoriel 5 x 4, répété trois fois. Les facteurs comprenaient cinq modes de plantation (4:0, 3:1, 2:2, 1:3 et 0:4 rangs de S. almum pour L. purpureus) et quatre dates d'association du lablab (0, 7, 14 et 21 jours après le semis - JAS - du sorgho fourrager). Les principaux indices de compétition calculés incluaient l'Équivalent Terre (LER), le Ratio de Compétition (CR), l'Agressivité (A), le Coefficient de Compétition Relative (K), la Perte de Rendement Réelle (AYL) et l'Indice d'Avantage Monétaire (MAI). L'association culturale a systématiquement démontré un avantage significatif en termes de rendement par rapport à la culture en pur, avec des valeurs moyennes totales de LER supérieures à l'unité pour tous les modes (1,79 - 1,83). Le mode de plantation 3:1 et le semis simultané (0 JAS) ont produit les LER les plus élevés (respectivement 1,83 et 1,96), indiquant des gains d'efficacité d'utilisation des terres de 83 à 96 %. Le sorgho fourrager était le compétiteur dominant, présentant des CR plus élevés et des valeurs A positives, tandis que le lablab était subordonné. Le Coefficient de Compétition Relative était le plus élevé dans le mode 2:2. Malgré quelques indications de perte de rendement par plante (AYL partielle négative), le système était économiquement rentable. L'Indice d'Avantage Monétaire le plus élevé (MAI = 412,39) a été obtenu avec le mode de plantation 3:1, confirmant sa supériorité économique. L'association de Sorghum almum avec Lablab purpureus est agronomiquement bénéfique et économiquement viable dans la Savane Guinéenne Nord. Pour une productivité et une rentabilité optimales, il est recommandé aux agriculteurs d'adopter un ratio de rangées de 3:1 et d'associer le lablab simultanément (0 JAS) avec le sorgho fourrager. Cette pratique améliore l'efficacité d'utilisation des terres et fournit une stratégie durable pour améliorer la production fourragère dans les systèmes culturaux-élevage des petits exploitants.

Mots-clés : *Sorghum almum ; Lablab purpureus* ; association culturale ; indices de compétition ; avantage monétaire

Introduction

The Nigerian economy has long been precariously dependent on revenue from crude oil, necessitating an urgent diversification towards sustainable and resilient agricultural production systems (CBN, 2021). This need is critically underscored by the skyrocketing costs of human food and animal feed, a direct consequence of low agricultural productivity and inefficiencies in traditional farming practices. To address this challenge, strategic investments in innovative and sustainable agricultural technologies are imperative. A pivotal trend in this transformation is the shift away from resource-intensive monoculture systems towards practices that achieve higher productivity, promote ecological sustainability, and enhance farmers' incomes (Aasim *et al.*, 2008). Among these, intercropping—the cultivation of two or more crops simultaneously on the same piece of land—has re-emerged as a cornerstone of sustainable agriculture, particularly within the savanna agro-ecology of Nigeria where it is integral to subsistence farming designed to meet escalating domestic food requirements (Oseni, 2010).

Cereal-legume intercropping systems are especially vital for developing sustainable food and fodder production, particularly in systems with limited access to external inputs like fertilizers and pesticides (Sadeghpour *et al.*, 2014). The benefits of such systems are multifarious, encompassing higher overall productivity and profitability (Lithourgidis *et al.*, 2011), improvement of soil fertility through biological nitrogen fixation and nutrient recycling by the legume component (Ghosh, 2004), more efficient utilization of light, water, and nutrients (Zhang *et al.*, 2011), reduced incidence of pests, diseases, and weeds (Ross *et al.*, 2005), and enhanced forage quality through the complementary effects of the combined species (Abdollah *et al.*, 2014). The success of an intercropping system, however, is contingent upon several factors, including the choice of compatible species, cultivar selection, planting density, spatial arrangement, and crucially, the relative sowing time of the component crops, all of which influence the intensity of interspecific competition (Dhima *et al.*, 2007; Esmaeili *et al.*, 2011). Forage sorghum, or Columbus grass (*Sorghum almum*), is a high-yielding, short-lived perennial valued for its rapid growth, drought tolerance, and production of palatable herbage suitable for silage, hay, and grazing (Muhammad, 1993). Despite its agronomic potential and documented compatibility with legumes, its cultivation remains underexploited in Nigeria. Lablab (*Lablab purpureus* L. Sweet) on the other hand is a highly nutritious, drought-tolerant legume that produces high-quality fodder (Amodu *et al.*, 2003). When conserved as hay or silage, it can significantly mitigate the weight loss experienced by livestock during the prolonged dry season, a major constraint to pastoral productivity in the region.

Approximately 80-90% of tropical livestock production depends on natural grasses, which are typically low in crude protein and have been degraded by chronic overgrazing. The scarcity of palatable and nutritious forage species necessitates the development of reliable, high-yielding grass-legume mixtures. Furthermore, there is a growing advocacy among farmers for organic and climate-smart practices like intercropping, which reduces reliance on expensive and environmentally detrimental inorganic fertilizers and pesticides. Since adequate nutrition is the primary determinant of meat and milk production, providing livestock with high-quality grass-legume forages is essential. The theoretical benefits of intercropping can only be realized through a precise understanding of the competitive interactions between component species, quantified using robust competition indices. Despite their significant potential, forage sorghum and lablab are among the most neglected crops in Nigeria, with a pronounced paucity of information on the optimal planting patterns and sowing schedules for their successful integration into an intercropping system. Therefore, the challenge is to identify the specific row arrangement and intercropping schedule that minimizes negative competition and sustains the potential yield of both species, thereby providing a scientific basis for effective crop-livestock integration. This study was designed to evaluate the competitive interactions and economic viability of intercropping forage sorghum with lablab. The specific objectives were to:

1. Evaluate the effect of different planting patterns on the competition indices of forage sorghum and lablab.
2. Determine the effect of varying days of intercropping lablab on the competition indices of forage sorghum and lablab.

Materials and Methods

Description of the experimental site

The study was conducted during the 2017 and 2018 rainy seasons at the experimental farm of Feeds and Nutrition Research Programme, National Animal Production Research Institute (NAPRI), Shika, Zaria. Shika is located on Latitude 11^0 12’W. Longitude 07^0 33’E and altitude 660m above sea level, 22km North-West of Zaria in the Northern Guinea Savannah zone of Nigeria (IAR, 2018). The climate of the study area is characterized by a defined wet and dry season. Wet season starts from April to early May and ends in late September to early October while the dry season from October to April. Long-term annual rain fall (2006-2016) ranges from 1110 to 1160mm with a maximum temperature of 37^0C in May and minimum temperature of 11.5^0C recorded in December/January and relative humidity of approximately 70% IAR (2018).

Meteorological data

The monthly rainfall pattern and relative humidity of Shika during the experimental period in 2017 and 2018 are presented in Figure 1 below, for both years initial rainfall started in May with 117.0mm in 2017 and 115.99mm in 2018. The peak of rain was observed in august each year and the highest rainfall was in august of both years. Rains ended in October of both years with little rains 4.6mm in 2017 and higher 29.41mm in 2018. The percentage relative humidity was above 70% in 2017 from July to October while in 2018 was from June to October. The mean annual rainfall of 159.18mm was recorded.

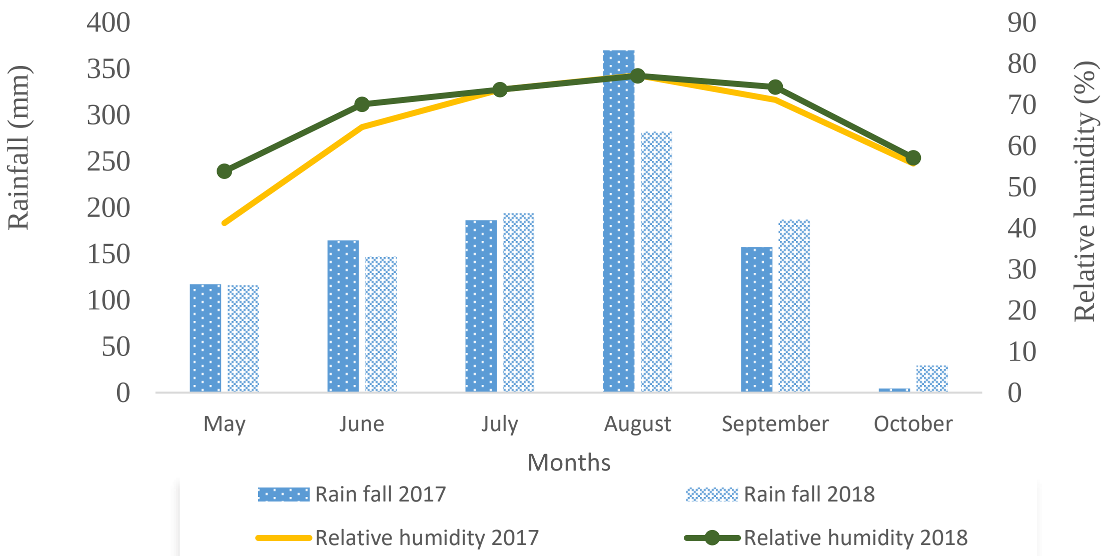

Figure 1: Rainfall pattern and Relative humidity of Shika in 2017 and 2018 seasons

Soil sampling and analyses

Soil samples were collected from the experimental site with the aid of soil auger at 4 corners and centers of the plots at 15 and 30cm depth and made a composite sample for soil analysis before the commencement of the experiment. The soil samples were analyzed for physical and chemical properties as described by AES (1998), to determine texture, particle size, total nitrogen, total carbon, phosphorus, soil pH and cation exchange capacity (CEC). The analysis was done at the Department of Soil Science, Faculty of Agriculture, Ahmadu Bello University, Zaria.

Experimental layout, Treatments and Design

A land area of 90 m x 18 m was used. The land was ploughed and harrowed twice to provide a clean seed bed and to enhance early seed germination. The experiment was laid out in a Randomized Complete Block Design (RCBD) with 5 x 4 x 3 factorial arrangement consisting of 5 planting patterns of forage sorghum: Lablab rows (4:0, 1:3, 2:2, 3:1 and 0:4) and 4 days of intercropping lablab (0, 7, 14 and 21 DAS) with 3 replicates. The experimental plot was subdivided into 5 main blocks (30 m x 18 m) each, with 2 m pathways which representing planting patterns. The blocks were subdivided into 4 sub-plots each measuring (6 x 4 m) with 1m pathways representing days of intercropping lablab, totalling 60 sub-sub plots.

Source of Experimental materials and Agronomic study

Forage sorghum (*Sorghum almum*) and *Lablab purpureus* (cv. white Rongai) seeds were sourced from the Feeds and Nutrition Research Programme, National Animal Production Research Institute (NAPRI) Shika, Zaria. Seeds of forage sorghum were planted on ridges at a spacing of 25 cm within rows and 85 cm between rows with 2 cm depth using seed rate of 15 kg/ha (Kallah *et al.,* 1999). Lablab seeds were treated with seed dressing chemical (Apron plus 50DS) at recommended rate of 2g to 2kg of seeds (Adegbite *et al.*, 2005). Lablab seeds were sown on hills in rows at 3 seeds per hole. First and second weeding was done manually with hoes at 3 and 6 weeks after sowing. The forage sorghum was thinned to 3 plants per stand after the first weeding and a uniform single dose of fertilizer was applied at the rate of 100 kg NPK (20:10:10) per hectare in two split doses.

Data collection

Competition Indices and Monetary Advantage

The competitive behavior of component crops in different planting patterns and days of intercropping for forage sorghum and Lablab was determined in terms of Land Equivalent Ratio (LER), Actual yield loss (AYL) Aggressivity (A), Relative Crowding Coefficient (KK), Competitive Ratio (CR) and Monetary Advantage Index (MAI).

The Land Equivalent Ratio (LER)

The LER is defined as the amount of land required under monoculture to obtain the same dry matter yield as produced in the intercrop (Mahapatra, 2011). The LER measures the effectiveness of intercropping in using the environmental resources compared to sole cropping. The Land equivalent ratio has been widely used as an index. Such calculation will reveal optimum intercropping patterns. LER was calculated for forage sorghum and Lablab in their mixtures according to Mead and Willey (1980) as follows:

LER total = $(LER_{sorghum} + LER_{lablab})$

Where $LER_{sorghum} = (Y_{si}/Y_{ss})$, and $LER_{lablab} = (Y_{li}/Y_{ls})$

Where Y_{ss} and Y_{ls} are the yields of forage sorghum and Lablab as sole crops respectively, and Y_{si} and Y_{li} are the yields of forage sorghum and Lablab as intercrops, respectively.

When LER is greater than 1.00, the mixed growing favors the growth and yield of intercropped species. The value indicates advantage through intercropping when the total LER value is greater than one. In contrast, when LER is lower than 1.00, the intercropping negatively affects the growth and yield of plants in mixtures (Dhima *et al.*, 2007; Yilmaz *et al.*, 2015), a disadvantage when the value is less than one and no effect when the value equals one.

Aggressivity (A)

Aggressivity is a measure of competitive relationships between two crops in mixed cropping (Oseni, 2010). This was expressed according to Dhima *et al.* (2007) as follows:

$A_{sorghum} = (Y_{si}/Y_{ss} \times Z_{sp}) - (Y_{li}/Y_{ls} \times Z_{lp})$ and $A_{lablab} = (Y_{li}/Y_{ls} \times Z_{lp}) - (Y_{si}/Y_{ss} \times Z_{sp})$.

Thus if $A_{sorghum} = 0$, both crops are equally competitive, if $A_{sorghum}$ is positive, then it is dominant and if $A_{sorghum}$ is negative, then forage sorghum is weak and vice visa.

Competitive Ratio (CR)

CR measures the ratio of individual LERs of the two component crops and the proportion in which they were sown in the mixture. This gives a more desirable competitive ability for the crops (Dhima *et al.*, 2007). The competitive ratio for forage sorghum and Lablab in mixture will be calculated by the formula proposed by Willey and Rao, (1980) as follows:

$CR_{sorghum} = (LER_{sorghum} / LER_{lablab}) (Z_{lp}/Z_{sp})$ and
$CR_{lablab} = (LER_{lablab}/LER_{sorghum}) (Z_{sp}/Z_{lp})$.

If the CR of forage sorghum is greater than the CR of lablab then, forage sorghum is more competitive than Lablab but if the CR of forage sorghum as less than that of Lablab then forage sorghum is less competitive and the reverse is true for Lablab species.

Relative crowding coefficient

Relative crowding coefficient (RCC) is a measure of relative dominance of one component crop over the other in an intercropping system. For crop 'a' in association with 'b': *K* measures the relative dominance of one species over the other in a mixture, several scholars gave the following detailed definition of *K* (Ghosh, 2004), which was calculated as follows:

K = (Kab x Kba)

Kab = (Yab x Xba) / (Yaa − Yab) x Xab

Kba = (Yba x Xab)/ (Ybb – Yba) x Xba

Where *X*ab is the sown proportion of 'a' in mixture of 'b' and *X*ba the sown proportion of 'b' in mixture of 'a'. If the product of the two coefficients; i.e. K = (Kab x Kba) is greater than 1, there is a yield advantage whereas if *K* obtained in the system equals to 1, there is no yield advantage, and if *K* in the system is less than 1, there is a yield disadvantage (Ghosh, 2004). Relative crowding coefficient (RCC) is a measure of relative dominance of one component crop over the other in an intercropping system. For crop 'a' in association with 'b'. Where Xab and Xba are the proportional land occupancies of cereals and legumes in intercropping, respectively. The dominant species has a higher *K* value and is more competitive in an intercropping system (Zhang *et al.,* 2011).

Actual yield loss (AYL)

The ATY is the proportionate yield loss or gain of intercrops in comparism to the respective sole crop. It takes into account of the actual sown proportion of the component crops with its sole stand (Yalmiz *et al.,* 2015). In addition, partial $AYL_{sorghum}$ or AYL_{Lablab} represent the proportionate yield loss or gain of each species when grown as intercrops relative to their yields in sole planting. The AYL was calculated using the following formular as described by Banik (1996).

$AYL = AYL_{sorghum} + AYL_{Lablab}$

Where $AYL_{sorghum} = ((Y_{sl} / Z_{sl}) / ((Y_{ss} / Z_{ss})) - 1$ and
$AYL_{lablab} = ((Y_{ls} / Z_{ls}) / ((Y_{ll} / Z_{ll})) - 1$,

Where Z_{sl} and Z_{ls} represent the sole proportion of intercrop forage sorghum with Lablab, Lablab with forage sorghum respectively. The AYL can have positive and negative values indicating an advantage or disadvantage of intercropping when the main purpose is to compare yield on a per plant basis.

Monetary Advantage Index (MAI)

The MAI the most important part of recommending a cropping pattern is the cost: benefit ratio more specifically total profit, because farmers are interested in the monetary value of return. The yield of all the crops in the different intercropping systems and also in sole cropping system and their economic returns in terms of economic value was evaluated to find out whether forage sorghum and additional Lablab yield are profitable or not. Their economic returns give an indication of the economic advantage of the intercropping system which will be calculated according to (Mahapatra, 2011) as follows:

MAI = ((monetary value of combined intercrops) x (LER – 1))/ LER.

The value of combined intercrops will be calculated as:

$Y_{sl} \times P_{sorghum} + Y_{ls} \times P_{Lablab}$.

The higher the MAI value the more profitable is the cropping system (Ghosh, 2004). Where $P_{forage\ sorghum}$ and P_{Lablab} are the commercial value of forage sorghum and Lablab respectively during the experimental period. Intercropping advantage values indicates the disadvantage of the system as the MAI values were in negative. On the other hand, monetary advantage index values were positive which showed a definite yield advantage in intercropping compared to sole cropping (Bantie *et al.,* 2014). Economic values of the seeds and forages of Sorghum and Lablab yields produced was estimated base on the average prevailing prices during 2017 and 2018 cropping season at the Feeds and Nutrition Research Programme, National Animal Production Research Institute, Shika-Nigeria.

Statistical analysis

Data collected for years 2017, 2018 and pooled for the two years were subjected to statistical analysis of variance using the General Linear Model Procedure of SAS (2005) package. Significant means were compared with least square means (LSMEANS) with the probability difference (PDIFF) option of the same SAS package at 95% confidence level.

Experimental model

$Y_{ijk} = \mu + P_i + D_j + (P \times D)_{ij} + E_{ijk}$

Where:

Y_{ijk} = is the record of observations for dependent variables

μ= is the population mean

P_i = effect of planting patterns of forage sorghum: lablab (i = 4:0, 1:3, 2:2, 3:1 and 0:4)

D_j = effect of days of intercropping (j = 0, 7, 14 and 21 DAS)

$(P \times D)_{ijk}$ = interaction effect of planting patterns and days of intercropping

E_{ijk} = Random error

Results

Soil Characteristics of the experimental site

The physical and chemical characteristics of the soil at the experimental site (0-15 cm depth) during the 2017 and2018 cropping season are shown in Table 1. The soil consists dominantly of 73.95 - 74.0 % sand, 16.20 - 16.50 % clay and 9.50 - 9.85 % silt respectively. The soil is well drained with organic carbon of between 0.75 - 0.90 %. The pH values of 5.2 and 5.1 for 0 - 15cm and 15-30cm respectively, shows that the soils are slightly acidic in nature. Typically, with tropical soils, the soil of the experimental site was deficient in both total nitrogen (0.12 - 0.2 %) and available phosphorus (90.4 - 96.4 ppm) which may require fertilization. The concentration of Zn was between 3.60 – 3.82 ppm and the exchangeable cations (meq/100g soil) present in the soil are Ca^{2+} (2.11-2.24), Mg^{2+} (0.73-0.82), K^+ (0.20-0.22) and Na^+ (0.12-0.17) needed for plant growth and development. The concentrations of Ca^{2+} seems to be higher than the other cations with Na^+ given the least concentration.

Table 1: Physical and Chemical Properties of Soil collected at the experimental site

	Soil depth (0-15cm)	
Physical properties	2017	2018
Particle size (%)		
Clay	16.20	17.50
Silt	9.85	7.50
Sand	73.95	75.0
pH ($CaCl_2$)	5.20	5.10
Chemical properties		
Total Nitrogen (%)	0.12	0.20
Organic carbon (%)	0.90	0.75
Zn (ppm)	3.82	3.60
P (ppm)	96.40	92.40
Exchangeable cation (meg/100g of soil)		
Ca^{2+}	2.25	2.41
Mg^{2+}	0.82	0.73

K^+	0.22	0.30
Na^+	0.17	0.22

Table 2: Land Equivalent Ratio (LER) of forage sorghum and Lablab as affected by planting patterns and days of intercropping

	Years of trial								
Years of trial	2017			2018			Pooled (2017-2018)		
Planting patterns	LERF. Sorg	LERLablab	LERTotal	LERF. Sorg	LERLablab	LERTotal	LERF. Sorg	LERLablab	LERTotal
FS:L (4:0)	1.0	-	1.0[b]	1.0	-	1.0[b]	1.0	-	1.0[b]
FS:L (3:1)	0.89	1.01	1.90[a]	0.92	0.83[b]	1.75[a]	0.91	0.92[ab]	1.83[a]
FS:L (2:2)	0.99	0.98	1.97[a]	0.94	0.67[c]	1.61[a]	0.96	0.83[b]	1.79[a]
FS:L (1:3)	0.97	0.88	1.85[a]	0.91	0.86[b]	1.77[a]	0.94	0.87[b]	1.81[a]
FS:L (0:4)	-	1.0	1.0[b]	-	1.0[a]	1.0[b]	-	1.0[a]	1.0[b]
SEM	0.08[NS]	0.07[NS]	0.12	0.06[NS]	0.04*	0.08*	0.07[NS]	0.06*	0.10*
Days of intercropping									
Same day	0.89	0.98	1.87	0.78[b]	1.07[a]	1.85[a]	0.84[b]	1.12[a]	1.96[a]
7 DAS	0.83	0.94	1.77	0.88[b]	0.76[b]	1.64[b]	0.85[b]	0.85[b]	1.70[b]
14 DAS	0.99	0.83	1.82	1.01[a]	0.74[b]	1.74[ab]	0.99[ab]	0.78[b]	1.78[b]
21 DAS	1.08	0.89	1.97	1.03[a]	0.59[c]	1.62[b]	1.05[a]	0.74[b]	1.79[b]
SEM	0.10[NS]	0.09[NS]	0.15[NS]	0.08*	0.05*	0.10*	0.09*	0.08*	0.09*
Interaction									
P x D	0.84	0.47	0.63	0.56	0.51	0.79	0.61	0.37	0.51

Means within a column followed by the same superscript letter are not significantly different (P>0.05). FS= forage sorghum, SEM standard error of mean, NS= not significant, CV=coefficient of variation, L = Lablab, D = days of intercropping, DAS = days after sowing forage sorghum.

Table 3: Competition Ratio (CR) of forage sorghum and Lablab as affected by planting patterns and days of intercropping

	Years of trial					
	2017		2018		Pooled (2017-2018)	
Planting patterns	CRF. Sorg	CRLablab	CRF. Sorg	CRLablab	CRF. Sorg	CLablab
FS:L (3:1)	4.32[a]	4.38[a]	4.75[a]	2.15[a]	4.55[a]	3.27[a]
FS:L (2:2)	1.36[c]	1.27[b]	1.57[c]	0.76[b]	1.47[c]	1.02[b]
FS:L (1:3)	3.35[b]	0.39[c]	3.61[b]	0.39[c]	3.48[b]	0.39[c]
SEM	0.24*	0.36*	0.16*	0.18*	0.20*	0.27*
Days of intercropping						
Same day	1.44[b]	2.75[a]	0.95[c]	1.69[a]	1.20[b]	2.22[a]
7 DAS	1.63[a]	2.37[a]	1.91[b]	0.92[b]	1.77[b]	1.61[b]
14 DAS	1.55[a]	1.50[b]	2.31[b]	1.04[b]	1.93[b]	1.27[b]
21 DAS	2.09[a]	1.36[b]	2.75[a]	0.75[b]	2.42[a]	1.06[b]
SEM	0.30*	0.45*	0.20*	0.23*	0.24*	0.30*
Interaction						
P x D	0.49	0.82	0.06	0.88	0.22	0.98

Means within a column followed by the same superscript letter are not significantly different (P>0.05). FS= forage sorghum, SEM standard error of mean, NS= not significant, CV=coefficient of variation, L = Lablab, D = days of intercropping, DAS = days after sowing forage sorghum.

Table 4: Aggressivity (A) of forage sorghum and Lablab as affected by planting patterns and days of intercropping

	Years of trial					
	2017		2018		Pooled (2017-2018)	
Planting patterns	A F. Sorg	A Lablab	A F. Sorg	A Lablab	A F. Sorg	A Lablab
FS:L (3:1)	2.52[a]	-2.52[b]	2.31[a]	-2.31[b]	2.42[a]	-2.42[b]
FS:L (2:2)	0.05[b]	-0.05[a]	0.41[b]	-0.41[a]	0.23[b]	-0.23[a]
FS:L (1:3)	2.61[a]	-2.61[b]	2.25[a]	-2.25[b]	2.43[a]	-2.43[b]
SEM	0.20*	0.20*	0.24*	0.24*	0.22*	0.22*
Days of intercropping						
Same day	-0.76[c]	0.76[a]	-1.09[c]	1.09[a]	-0.93[c]	0.93[a]
7 DAS	0.072[b]	-0.072[b]	0.18[b]	-0.18[b]	0.13[b]	-0.13[b]
14 DAS	0.47[a]	-0.47[c]	0.48[a]	-0.48[c]	0.48[a]	-0.48[c]
21 DAS	0.41[a]	-0.41[c]	0.54[a]	-0.54[c]	0.48[a]	-0.48[c]
SEM	0.25*	0.25*	0.30	0.30*	0.28*	0.28*
Interaction						
P x D	0.35	0.35	0.55	0.55	0.67	0.67

Means within a column followed by the same superscript letter are not significantly different (P>0.05), FS= forage sorghum, SEM standard error of mean, CV=coefficient of variation, L = Lablab, D = days of intercropping, DAS = days after sowing sorghum.

Table 5 Relative Crowding Coefficient (RCC or K) of forage sorghum and Lablab as affected planting patterns and days of intercropping

	Years of trial								
	2017			2018			Pooled (2017-2018)		
Planting patterns	Kf.sorg	Klablab	K1	Kf.sorg	K.lablab	K2	Kf.sorg	K.lablab	K3
FS:L (3:1)	-4.68[b]	9.01[a]	-42.17[b]	0.46[b]	-5.56[c]	-2.56[b]	-2.11	1.73[a]	-3.65[c]
FS:L (2:2)	-11.52[c]	0.41[b]	-4.72[a]	1.22[a]	-1.92[b]	-2.34[b]	-5.15	-0.76[b]	3.91[a]
FS:L (1:3)	2.81[a]	-0.18[c]	-0.51[a]	-1.40[b]	-0.59[a]	0.83[a]	-1.97	-0.39[b]	0.77[b]
SEM	8.08	6.08	4.13	5.36	3.73	2.50	4.48[NS]	1.56	1.20
Days of intercropping									
Same day	-2.13[b]	-4.55[c]	9.69[a]	5.27[a]	-6.22[c]	-32.78[c]	1.57[b]	-5.39[c]	-8.46[c]
7 DAS	-0.27[b]	0.85[b]	-1.81[c]	-0.70[b]	-18.49[d]	12.94[a]	-0.49[c]	-8.82[d]	4.32[b]
14 DAS	-15.72[c]	6.72[a]	-105.64[d]	-9.64[c]	12.32[a]	-118.76[d]	-12.68[d]	9.52[a]	-120.71[d]
21 DAS	0.26[a]	9.29[a]	2.42[b]	5.44[a]	1.62[b]	8.81[b]	2.86[a]	5.46[b]	15.62[a]
SEM	4.04	3.04	2.07	2.68	1.87	1.25	2.24	0.78	0.60
Interaction									
P x D	0.88	0.78	0.78	0.10	0.52	0.08	0.37	0.72	0.07

Means within a column followed by the same superscript letter are not significantly different (P>0.05), FS= forage sorghum, SEM standard error of mean, CV=coefficient of variation, L = Lablab, D = days of intercropping, DAS = days after sowing sorghum.

Table 6: Effect of planting patterns and days of intercropping on Actual Yield loss (AYL) of forage sorghum and Lablab in sole and intercrop

	Years of trial								
Years of trial	2017			2018			Pooled (2017-2018)		
Planting patterns	AYLF. Sorg	AYLLablab	AYLTotal	AYLF. Sorg	AYLLablab	AYLTotal	AYLF. Sorg	AYLLablab	AYLTotal
FS:L (3:1)	-0.33[b]	-0.12[a]	-0.45[b]	-0.10	-0.13[a]	-0.24	-0.17[b]	0.37[b]	0.21[a]
FS:L (2:2)	-0.19[a]	-0.14[a]	-0.34[a]	-0.08	-0.29[b]	-0.38	-0.08[a]	0.24[c]	0.17[b]
FS:L (1:3)	-0. 14[a]	-0.24[b]	-0.45[b]	-0.12	-0.09[a]	-0.21	-0.55[c]	1.74[a]	0.19[b]
SEM	0.06*	0.06*	0.09*	0.05[NS]	0.06	0.09[NS]	0.055*	0.06*	0.12*
Days of intercropping									
Same day	-0.28[b]	0.02[a]	-0.26[a]	-0.24[c]	0.10[a]	-0.14[a]	-0.23	0.75	0.52
7 DAS	-0.27[b]	-0.20[b]	-0.48[b]	-0.14[c]	-0.19[b]	-0.34[b]	-0.34	0.81	0.45
14 DAS	-0.17[a]	-0.22[b]	-0.45[b]	-0.02[a]	-0.23[c]	-0.25[a]	-0.25	0.80	0.55
21 DAS	-0.14[a]	-0.28[b]	-0.36[b]	-0.001[a]	-0.38[d]	-0.38[b]	-0.23	0.78	0.55
SEM	0.05*	0.05*	0.07*	0.04*	0.05	0.07*	0.04[NS]	0.05[NS]	0.09[NS]
Interaction									
P x D	0.73	0.40	0.82	0.46	0.86	0.83	0.53	0.02	0.11

Means within a column followed by the same superscript letter are not significantly different (P>0.05), FS= forage sorghum, SEM standard error of mean, CV=coefficient of variation, L = Lablab, D = days of intercropping, DAS = days after sowing sorghum.

Table 7: Effect of planting patterns and days of intercropping on Monetary Advantage Index (MAI) of forage sorghum and Lablab in sole and intercrop

	Years of trial		
	2017	2018	Pooled (2017-2018)
Planting patterns	MAI	MAI	MAI
FS:L (3:1)	270.37[b]	554.40[a]	412.39[a]
FS:L (2:2)	300.90[a]	460.30[b]	380.60[a]
FS:L (1:3)	251.97[c]	463.80[b]	357.89[b]
SEM	14.08*	26.05*	20.07*
Days of intercropping			
Same day	326.77[a]	642.30[a]	484.54[a]
7 DAS	207.62[d]	374.80[d]	291.21[c]
14 DAS	261.40[c]	526.80[b]	394.10[b]
21 DAS	301.87[b]	427.50[c]	364.69[b]
SEM	10.56*	19.54*	15.05*
Interaction			
P x D	0.69	0.39	0.57

Means within a column followed by the same superscript letter are not significantly different (P>0.05), FS= forage sorghum, SEM standard error of mean, CV=coefficient of variation, L = Lablab, D = days of intercropping, DAS = days after sowing sorghum.

Discussion

The comprehensive analysis of competition indices provides a deep understanding of the biological interactions and economic viability of intercropping forage sorghum with lablab. The results from this two-year study demonstrate that this system is not only agronomically productive but also economically advantageous in the Northern Guinea Savanna of Nigeria. The differential responses to planting patterns and sowing dates underscore the critical role of management practices in optimizing the balance between competition and complementarity.

Land Use Efficiency and System Productivity

The Land Equivalent Ratio (LER) is the paramount index for evaluating the efficiency of an intercropping system, quantifying the land area required under sole cropping to produce the yield achieved by intercropping (Mead and Willey, 1980). In this study, the total LER values for all intercropping patterns were consistently and significantly greater than unity (Pooled data: 1.79 - 1.83). This indicates a substantial yield advantage, meaning intercropping required 79% to 83% less land than monoculture to produce an equivalent amount of total biomass. This high land-use efficiency is a hallmark of successful cereal-legume associations, primarily due to the complementary use of resources such as light, water, and nutrients (Lithourgidis *et al*., 2011). The tall, fast-growing C4 forage sorghum efficiently captures sunlight, while the leguminous lablab contributes to soil nitrogen through biological fixation, reducing interspecific competition for this key nutrient (Ghosh, 2004).

The highest total LER (1.96) was achieved when both crops were sown simultaneously (0 DAS). This suggests that a full co-growth period maximizes overall resource capture and biomass accumulation, despite the initial competitive pressure. This finding aligns with Hussain *et al.* (2002), who reported superior LER in simultaneous sowing of sorghum and cowpea. Among planting patterns, the 3:1 and 2:2 configurations were most effective. The high

LER in the 3:1 pattern is particularly significant as it demonstrates that a higher proportion of the more valuable cereal can be maintained without sacrificing system-level productivity, a key consideration for farmers.

Competitive Dynamics and Dominance

The Competitive Ratio (CR) and Aggressivity (A) indices offer critical insights into the nature of the competition between the component species. The consistently higher CR values for forage sorghum across all planting patterns (4.55 in 3:1 pattern) confirm its role as the dominant competitor in this association (Table 3). This is a common phenomenon where cereals, with their faster canopy establishment and taller stature, typically outperform legumes in competing for light (Oseni, 2010).

The Aggressivity results (Table 4) further reinforce this conclusion. The persistent positive A values for forage sorghum and negative values for lablab across most treatments unequivocally identify sorghum as the aggressive, dominant species and lablab as the subordinate, suppressed one. The most aggressive behaviour by sorghum was observed in the 3:1 and 1:3 patterns. This indicates that in both cereal-dominant and legume-dominant stands, the minority component faces intense competition, leading to high per-plant aggression values. This aligns with the findings of Dhima *et al*. (2007), who observed that skewed planting ratios often intensify the competitive dominance of one species.

The significant effect of sowing date reveals a crucial management insight. When lablab was sown simultaneously (0 DAS), it initially exhibited strong competitiveness, even dominating sorghum (negative aggressivity for sorghum). This suggests that lablab's early growth vigour can challenge sorghum if established together. However, as the intercropping delay increased to 14 and 21 DAS, sorghum's dominance became absolute. This is because a head start allowed sorghum to establish a canopy and root system, pre-empting resources and strongly suppressing the later-emerging lablab. This supports the concept of "relay intercropping," where a delayed sowing of the secondary crop can be used to manage competition and benefit the primary crop (Iqbal *et al*., 2019). Our results posit that forage sorghum is an excellent primary crop in such a system.

Yield Stability and Economic Profitability

The Relative Crowding Coefficient (K) and Actual Yield Loss (AYL) provide a more nuanced view of yield advantages. The variable and often negative K values (Table 5) suggest intense interspecific competition, particularly in the 3:1 and 1:3 patterns, where one species is disproportionately represented. This intensity can sometimes lead to a yield disadvantage on a relative crowding basis, as the dominated species is unable to realize its full yield potential (Weigelt and Jolliffe, 2003).

In contrast, the positive total AYL values in the pooled data (Table 6: 0.17-0.21) are a strong indicator of the net absolute yield benefit of the intercropping system at the plot level. This means that while an individual lablab plant may yield less than its sole crop counterpart (negative partial AYL), the system as a whole produces more total biomass per unit area. This is the primary goal of intercropping and confirms that the system offers a genuine yield advantage despite the competitive pressure (Banik, 1996).

The ultimate metric for farmer adoption is economic viability. The consistently positive values for the Monetary Advantage Index (MAI) across all intercropping treatments provide compelling evidence for the profitability of this system (Table 7). The highest MAI was recorded in the 3:1 planting pattern (412.39). Crucially, the highest MAI value (484.54) was achieved with simultaneous sowing (0 DAS), despite the highly competitive pressure this creates. This indicates that while a sowing delay may optimize certain biological indices for the primary crop (sorghum's aggressivity), the highest economic return is generated by maximizing total seasonal biomass production from *both* crops, which is best achieved by giving both a full growing season. This finding is vital for extension recommendations, as it demonstrates that the most profitable option is also operationally the simplest. This result corroborates the work of Lithourgidis *et al*. (2011), who concluded that cereal-legume intercropping consistently offers significant economic advantages over sole cropping.

Conflict of interest

No conflict of interest by the authors.

Conclusion

Based on the results of this two-year study evaluating the competition indices of intercropping *Sorghum almum* with *Lablab purpureus* in the Northern Guinea Savanna of Nigeria, the following conclusions are drawn:

1. Significant Land Use Efficiency: Intercropping forage sorghum with lablab is unequivocally more productive than sole cropping, as evidenced by Land Equivalent Ratio (LER) values significantly greater than unity (1.79 - 1.96). This demonstrates that intercropping can produce the same yield as monocropping on just 52-56% of the land, freeing up to 44-48% of land for other uses and providing a powerful strategy for sustainable land intensification.
2. Clear Competitive Hierarchy: Forage sorghum is the dominant species in this intercropping system, consistently exhibiting a higher Competitive Ratio (CR > 1) and positive Aggressivity (A) values. Lablab acts as the compatible, subordinate species. This hierarchy must be managed, not overcome, for optimal system performance.
3. Sowing Date as a Critical Management Tool: The timing of lablab introduction is a decisive factor for balancing the competition. Simultaneous sowing (0 DAS) maximizes total system productivity (highest LER) but favors initial lablab competitiveness. In contrast, delaying lablab sowing until 21 days after sorghum (21 DAS) strongly reinforces sorghum's dominance and optimizes its yield share within the mixture.
4. Economic Viability is Achievable: All intercropping treatments were economically advantageous over sole cropping, with positive Monetary Advantage Index (MAI) values. The 3:1 planting pattern emerged as the most economically superior system, offering the highest financial returns and proving that intercropping is not just biologically efficient but also financially profitable for farmers.
5. Optimal Configuration for Northern Guinea Savanna: The most robust and beneficial intercropping system for smallholder farmers in this agro-ecology is achieved by combining a 3:1 row ratio (sorghum: lablab) with the simultaneous sowing (0 DAS) of both crops. This configuration successfully balances high land productivity, economic return, and operational simplicity.

Recommendations

To translate these research findings into actionable practice for enhancing forage production and livestock nutrition in the Northern Guinea Savanna, the following recommendations are made:

1. For Farmers and Cooperative Societies:
    - Adopt the 3:1 Intercropping Pattern: Farmers should prioritize planting three rows of forage sorghum to one row of lablab to achieve the best balance between high sorghum

yield and beneficial legume integration.

- Sow Both Crops Simultaneously: For the highest total biomass yield and greatest economic return, forage sorghum and lablab seeds should be planted on the same day. This practice is operationally simpler and maximizes land use efficiency throughout the growing season.
- Utilize the System for Dry Season Feeding: Farmers should harvest and conserve the resulting high-quality forage as hay or silage. This will directly address the critical challenge of weight loss in ruminants during the dry season by providing a protein-rich feed supplement.

2. For Policy Makers and Extension Agencies (ADP, State Ministries of Agriculture):
   - Promote and Disseminate this Technology: This specific sorghum-lablab intercropping model should be integrated into farmer education and extension packages as a proven method for sustainable forage production.
   - Initiate Demonstration Plots: Establish demonstration plots across the savanna zone using the recommended 3:1 pattern and simultaneous sowing to visually convince farmers of the system's advantages in yield and profitability.
   - Encourage Climate-Smart Agriculture: Policy should favor and incentivize legume-based intercropping systems like this one, which reduce the reliance on synthetic nitrogen fertilizers, improve soil health, and contribute to more resilient farming systems.
3. For Research Institutes and Universities:
   - Investigate Complementary Agronomic Practices: Future research should build on these findings to determine the optimal fertilizer regime and water management practices specifically for this intercropping system to further boost productivity.
   - Explore Mechanization and Value Addition: Research should focus on developing small-scale mechanization for planting and harvesting this specific row configuration and on innovating value-added products from the forage mix to increase profitability.
   - Conduct On-Farm Adaptive Trials: Researchers should validate these station-based findings through on-farm adaptive trials in different localities within the Northern Guinea Savanna to ensure wide applicability and farmer acceptance.

By implementing these recommendations, the potential of forage sorghum and lablab can be fully unlocked, leading to enhanced productivity, increased incomes for smallholder farmers, and improved sustainability of the crop-livestock production system in Nigeria.

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