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AGRONOMIC PERFORMANCE AND COMPETITION INDICES IN FONIO-MAIZE INTER-CROP UNDER RAIN-FED CONDITIONS

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Abstract: The investigation was to analyze for yield characters and competition indices in fonio-maize intercrop. NCRIACH2 fonio and DMR-SR maize were deployed, inter-cropping arrangement was in eleven proportions, having 10 rows of planting patterns. Higher land productivity and greater resource efficiency through increased yield and crop diversification were generally observed. 1F:1M combination recorded 32% advantage in land productivity, while 3F:1M has 1.55, showing significant land-use efficiency when fonio constitutes 75% of the system. FM 100:100 combination system indicated that maize and fonio can complement each other. 1F:3M system resulted in reduced fonio performance due to maize's dominance. Relative Crowding coefficient values confirm that maize has higher competitive pressure on fonio than vice versa. 1F:2M and 2F:2M systems could potentially balance for crop yield while optimizing space, nutrients, and water usage. Farmers in rain-fed areas are encouraged to adopt inter-cropping systems, particularly those with a balanced ratio of fonio and maize.

Keywords: combination system, competition indices, fonio, intercrop, maize, performance, resources.

Introduction

Fonio crop is often identified amongst small millet biodiversity. The ancient cereal is native to savanna zone of West Africa where CRUZ (2004) dates the cultivation back to 5,000 BC. Fonio, mostly called Acha in Nigeria belongs to the family Poacea, it is a C_4 annual and free-tillering herbaceous plant [ADOUKONOU-SAGBADJA, 2010] and may grow to the heights of 150 cm having a potential yield of 1.3 t/ha. The crop demonstrates high tolerance to most biotic and abiotic stresses. It is often grown in uneven marginal lands that are shallow and poor in fertility with low moisture retention capacity. In low rainfall arid regions where the crop is mostly grown, small holder farmers rely mostly on rainfed conditions for cultivation. KWON-NDUNG & al. (1998) opined that there are over 300 species in the genera, however, ISONG & al. (2022) identified two species (*Digitaria exilis* (Kippist) Stapf and *D. iburua* Stapf) as cultivated in Nigeria, mostly in the Northern regions of the country. Improved crop management practices are scarcely adopted by the farmers due to socio-economic constraints. While Nigeria and Guinea are leading in production and hectares of cultivation, the crop is highly challenged by strong competition from maize and other commodity crops in the country.

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Maize (*Zea mays* L.) in the other hand is an essential cereal crop in Nigeria being a better option to mitigate food shortage and a prominent source of carbohydrates, proteins, vitamins and minerals competing favorably with other starchy crops like rice and yams [OLANIYAN, 2015]. Sufficient supply of macro nutrients like nitrogen, phosphorus and potassium are essential for optimum growth and yield of maize while long-term cultivation impacts on soil organic matter and nutrient availability in the soils [MALO & al. 2005]. The suitability of maize to diverse environments is unmatched by any other crop. SHAW (1988) however noted that maize is grown from 58°N to 40°S, from below sea level to altitudes higher than 3000 m, and in areas with 250 mm to above 5000 mm of rainfall per year.

Farmers in their quest to improve adaptability, productivity and sustainability, have practiced different cropping systems [HAUGGARD-NIELSON & JENSEN, 2001]. WILLEY & OSIRU (1972) observed that primary focus was on monocropping. The exigency of climate change, population increases, industrialization and food preferences have placed demand on production of more food and feed, using less resource, time and water while maximizing the available nutrients. Therefore, for better resource use efficiency and moving towards agricultural sustainability, BEETS (1977) and DARIUSH & al. (2006) agreed that inter-cropping systems of agricultural production can be effective and sustaining. SANCHEZ (1976) had earlier define inter-cropping as a method of growing two or more crops in the same field at the same time. It is the practice of growing more than one crop simultaneously in alternating rows of the same plot [BEETS, 1990]. However, authors like BLADE (1992) and TSUBO & al. (2005) noted the gradual recognition of the importance of inter-cropping system due to its role in subsistence food production especially in developing countries. Other prominent potential of this kind of cropping system include improvement in utilization of growth resources by the inter-cropped species [BANIK & al. 2006], control of weeds, insect/diseases [SMITH & McSORLEY, 2000], control of soil erosion and conservation [JABBAR & al. 2009; MATUSSO & al. 2012], lodging resistance and total yield increment. MEAD & WILLEY (2008) however summarized that Inter-cropping is often used to increase the overall farm productivity per unit area. The system sometimes result in either positive or negative interactions among the component crops. GHOSH (2004) observed that where there is positive interaction, the component crops facilitate each other to achieve maximum productivity, while negative interaction results in yield reduction of the less competitive crop in the interaction. Interactions reported on inter-cropping system between cereals and legumes are widely available, however interactions in all cereals inter-cropping system is scarcely exploited.

Several authors [WILLEY & RAO, 1980; ESMAEILI & al. 2011; GHOSH, 2004; NDAKIDEMI & DAKORA, 2007; NYOKI & NDAKIDEMI, 2016], had itemized the use of some indices and methods to estimate the interaction among the component species. Land equivalent ratio (LER), the relative land area under sole crops that is required to produce same yields as in an in inter-cropping system is regarded as the measure of land use efficiency of the plants. HALL (1974) proposed relative crowding coefficient (RCC or K) as a measure of a crop producing more or less than expected in an inter-crop system. It is a measure of relative dominance of a crop over the other. A value of 1, less than 1 or greater than 1 signifies equal yield, less yield or greater yield than the expected yield respectively. While competitive ratio (CR) represents the ratio of individual land equivalent ratios of two crops, considering the proportion initially sown, Agrgressivity (A) measures the value by which the relative yield increase of one crop is greater than that of the other crop. The Actual Yield Loss (AYL) indices is based on yield per plant, BANIK & al. (2000) is of the opinion that it presents a more accurate information about the competition than other indices. Inter-cropping Advantage (IA) and

Monetary Advantage Indices are formulated to provide information on the economic advantage of the inter-cropping systems. Therefore, this investigation thus seek to study the performance of yield and other characters, and to analyze for the different competition indices present in fonio-maize inter-cropping systems under rain-fed conditions

Material and methods

Location and environmental condition of the experimental site

The Inter-cropping experiment was conducted at National Cereals Research Institute experimental fields, located at Badeggi, about 10 kilometers from Bida in Niger State, Nigeria. National Cereals Research Institute is at Latitude 9°45'N and Longitude. 6°07'E in the Southern Guinea Savannah, at an elevation of 98 m a.s.l. The experiment took place during the growing season (June-November) of 2022 and 2023, the climatic and edaphic conditions were typical of the Southern Guinea savanna.

Experimental material, design and crop management

The experimental materials used include a Fonio variety NCRIACH2, sourced from the National Cereals Research Institute (NCRI) gene bank and a Maize variety DMR-SR from National Centre for Genetic Resources and Biotechnology (NACGRAB) collections. Randomized Complete Block Design (RCBD) was employed and replicated three (3) times. The plot size of 3 m x 5 m was used, planting distance of 30 cm and 50 cm was adopted for both sole crop and inter-crop for fonio, and the plant density of 80,666 plants per hectare was maintained. Maize was planted at a spacing of 25 cm x 100 cm both in sole crop and inter-crop. However, in both crops, pure culture was inserted to serve as control treatment. The inter-cropping arrangements were in eleven (11) arrangements, formulated as indicated in Table 1, having 10 proportions of different crop combinations representing planting ratios of fonio to maize, FNMZ, 1F:1M, 2F:1M, 2F:2M, 1F:2M, 1F:3M, 3F:1M, 3F:2M and 2F:3M. Manual weeding was adopted, two times weeding at 30 DAP and at 60 DAP.

Observation, data collection and statistical analysis

Observation and data collection on test crop (fonio) were on days to 50% flowering (DFF), number of tillers per plant (NTPP), number of panicles per plant (NPPP), plant height (PH), spike length (SL), panicle length (PL), number of spikes per panicle (NSPP), days to maturity (DM), weight of panicle (PW) and grain yield (GY) expressed in kilogram per hectare. Also. observation and data collection on maize plants were on plant height (PH), number of ears per plant (NEP), number of rows per ear (NRE), number of grains per row (NGR), number of grains per ear (NGE), number of grains per plant (NGP), one thousand grain weigh (1000GW) and grain yield (GY). The Grain Yield of fonio and that of maize were as well presented in tons per hectare, the value of each crop per hectare was determined based on the prevailing market price of the two crops. Statistical Tool for Agricultural Research (STAR) version 2.0.1 (2014) was used for the analysis of yield and the yield characters in both the test crop and component crop. *Per se* performance of the crops at different planting combination systems for each of the traits were determined, analysis of variance was carried out and means were separated using Duncan Multiple Range Test (DMRT).

Competition indices and monetary advantage determination

Grain Yield of fonio and maize were as well presented in tons per hectare, the value for each of the crop per hectare was determined as follows:

$$V_f = Y_f \times P_f$$

where, V_f = *Value of fonio*; Y_f =*Yield of fonio in tons per hectare*; P_f = *Prevailing market price of fonio during the time of harvest.*

$$V_m = Y_m \times P_m$$

where, V_m = *Value of Maize*; Y_m =*Yield of maize in tons per hectare*; P_m = *Prevailing market price of maize during the time of harvest.*

The measure for mixed stand advantage was expressed in Land Equivalent Ratio (LER), which is an inter-cropping efficiency over mono-cropping in the use of environmental resources. This was obtained by dividing the inter-cropped yield by mono-crop yield for each crop in inter-cropping system. The total LER is by adding the partial LERs together. According to WILLEY (1979), when the value of LER is greater than one, more sole crop's land is necessary for a given yield value. But when it is less than one, the indication is that inter-cropping is negatively affecting the growth and yield of component crops in mixtures. The value of LERs were worked out following the formula of DHIMA & al. (2007) as follows:

$$L = L_1 + L_2 = L_{i1} / L_{s1} + L_{i2} / L_{s2}$$

where, L_1= *LER of Fonio*; L_2 = *LER of Maize*; Y_{i1} = *Yield of Fonio in intercrop*; Y_{i2} = *Yield of Maize in intercrop*; Y_{s1} = *Yield of Fonio in sole cropping*; Y_{s2} = *Yield of Maize in sole cropping.*

The relative dominance of a crop over the other measured by the Relative Crowding Coefficient (K) was calculated following the formula by DE WIT (1960). DHIMA & al. (2007) also hinted that when the value is 1, it means there is no yield advantage in the system. However, when the K value is greater than or less than 1, the yield advantage is recorded or there is yield disadvantage respectively:

$$K = (K_{fonio} \times K_{maize})$$

$$K_{fonio} = Y_{fm} \times R_{mf} / [(Y_f - Y_{fm}) \times R_{fm}]$$

$$K_{maize} = Y_{mf} \times R_{fm} / [(Y_m - Y_{mf}) \times R_{mf}]$$

Where, K_{fonio} = *Relative Crowding Coefficient of Fonio in the Intertaction*; K_{maize} = *Relative Crowding Coefficient of Maize in the interaction*; Y_{fm} = *Yield of fonio in the interaction*; Y_{mf} = *Yield of maize in the interaction*; R_{fm} = *Ratio of fonio in the interaction*; R_{mf} = *Ration of maize in the interaction*; Y_f = *Yield of sole fonio*; Y_m = *Yield of sole maize*.

ESMAEILI & al. (2011) expressed the Competitive Ratio (CR) as the ratio of individual LERs of two crops, taking into consideration the proportion of the species initially planted. Also, the index was determined according to the method of DHIMA & al. (2007) as follows:

$$CR_{fonio} = (LER_{fonio} / LER_{maize})(R_{mf}/R_{fm})$$

$$CRmaize = (LER_{maize} / LER_{fonio})(R_{fm}/R_{mf})$$

where, CR_{fonio}= *Competitive Ratio of Fonio in the interaction*; CR_{maize} = *Competitive Ratio of maize in the interaction*; LER_{fonio} = *Land Equivalent Ratio of fonio in the interaction*; LER_{maize} = *Land Equivalent Ratio of maize in the interaction*; R_{fm} = *Ratio of fonio in the interaction*; R_{mf} = *Ratio of maize in the interaction*

Another index was the Aggressivity (AGG or A). This is a measure of how much the relative yield in one crop is greater than that for another crop in an inter-cropping system according to McGILCHRIST (1965). Aggressivity value of 0 denotes equal competition in both crops. A positive or negative value of Aggressivity inferred that the crop is dominant or being dominated respectively. The following formular were adopted to determine aggressivity as follows:

$$A_{fonio} = (Y_{fm} / Y_f \text{ x } R_{fm}) – (Y_{mf} / Y_m \text{ x } R_{mf})$$

$$A_{maize} = (Y_{mf} / Y_m \text{ x } R_{mf}) – (Y_{fm} / Y_f \text{ x } R_{fm})$$

where, A_{fonio} = *Aggressivity of Fonio in the interaction*; A_{maize} = *Aggressivity of Maize in the Interaction.*

Actual Yield Loss (AYL) index was also formulated. This index is based on yield per hectare, the proportionate loss or gain of yield in inter-crop compared to the respective sole species. AYL factors in yield per plant and the real proportion of the component species planted with that of the sole stand. The actual Yield Loss can be either a positive or negative in value, which signifies advantage or disadvantage inter-cropping relationship. The following formular were used to determine Actual Yield loss for fonio and maize in the inter-cropping interaction as demonstrated by KHONDE & al. (2018):

$$AYL = AYLf_{onio} + AYL_{maize}$$

$$AYL_{fonio} = [(Y_{fm} / R_{fm}) / (Y_f / R_f)] -1$$

$$AYL_{maize} = [(Ymf / R_{mf}) / (Y_m / R_m)] -1$$

where, AYL_{fonio} = *Actual yield loss of fonio in the interaction*; AYL_{maize} = *Actual yield loss of maize in the interaction.*

Two indices that provided information on the economic advantage of the inter-cropping systems were as well considered. One is Inter-cropping Advantage (IA), formulated according to the method of BANIK & al. (2000) as follows:

$$IA_{fonio} = AYL_{fonio} \times P_{fonio}$$

$$IA_{maize} = AYL_{maize} \times P_{maize}$$

where, IA_{fonio} = *Intercropping Advantage for fonio*; IA_{maize} = *Intercropping Advantage for Maize*; P_{fonio} = *Current commercial Price of fonio* (*₦800 per Kg*); P_{maize} = *Current commercial Price of Maize* (*₦300per Kg*).

Another economic Advantage index is the Monetary Advantage Index (MAI), which according to GHOSH (2004), the higher the MAI value the more profitable is the cropping system. This index was formulated as follows:

$$MAI = [(\text{value of combined intercrops}) \text{ x } (LER - 1)] /LER$$

Results and discussions

The data for environmental and soil conditions of the experimental location for 2022 and 2023 growing seasons are presented in Figures 1, 2, 3a, 3b and 3c. While Figure 1 is the rainfall pattern during the growing seasons at Badeggi, Figure 2 shows the temperature variation and Figure 3a, 3b and 3c present the soil physical properties, soil chemical properties and soil exchangeable ions for the experimental plots. Patterns of inter-cropping arrangements are in Table 1. *Per se* performance of fonio and maize parameters as affected by the inter-cropping system are in Tables 2 and 3 respectively. Also, competition indices for sole stands and fonio-maize inter-crop in 2022 and 2023 seasons are presented in Table 4.

The planting combination 2F:1M and 3F:2M representing 67% fonio, 33% maize and 60% fonio, 40% maize respectively were the first to reach 50% flowering. The increase in days to flowering in 1F:3M suggests competition of maize with fonio for limited resources thereby causing flowering in fonio to delay. According to GHOSH & al. (2006), the delay could affect the overall productivity of fonio because the growing period is shortened. However, the 1F:2M and 2F:3M systems shows closer flowering times to sole fonio (107 days), indicating that reproductive timing in fonio is not severely hindered by the presence of maize. Planting combination 2F:1M recorded highest number of tillers per plant (27.80) and longest panicles (25.20). Inter-cropping systems having higher or equal fonio proportions with maize induce greater vegetative growth. This is in alignment with the findings of WILLEY (1979), suggesting that inter-cropping can enhance plant density and increased tillering ability. Meanwhile, authors like BIABANI & al. (2008), SADEGHPOUR & JAHANZAD (2012) suggested an advantage of inter-cropping systems in final yield as dependent on spatial arrangements of participating species. The robust number of panicles observed in 3F:1M system is an indication of a balanced competition for resources, indicating a beneficial combination for reproductive growth of fonio, corroborating the findings of JACKSON (1980). Increase in spikes and panicles in the FM 100:100 system may also suggest that maize is more dominant, leading to enhanced growth for both crops, but limiting potentials in fonio. Tallest fonio plants (167.93 and 150.40) were found in FM 100:100 and 50:50 combinations respectively. The inter-cropping systems that combine both crops at relatively equal proportions also appear to mature earlier. inter-cropping systems where maize proportion is high also appear to out-competes fonio. However, the 1F:3M system shows that when fonio is at a low proportion, it struggles to grow to its potential height confirming the discussion by WEINER (1990). Similarly, FM 100:100 combination seems to enhance the panicle weight of fonio, demonstrating better growth conditions for both crops in a balanced inter-cropping system. It also suggests synergistic effects between maize and fonio but in combination systems with relatively equal ratios.

Fonio in FM 100:100 system performance was as well good, having positive effects on number of panicles and number of spikes due to equal space allocation as suggested by SHAH & al. (2021). Also, in this system, both crops mature earlier, suggesting a positive interaction, in agreement with OFORI & STERN (1987) that in inter-cropping, earlier maturation due to complementary growth are likely to occur.

Planting pattern of 3 rows fonio and 1 row maize recorded highest number of panicles per plant and gave the highest grain yield of 555.47 kg/ha behind sole fonio crop of 637.90 kg/ha. Sole fonio yielded the most grain, which could indicate that fonio grows best without competition from maize. However, in FM 100:100 inter-cropping systems, fonio yields relatively high, suggesting positive interaction. The highest yield in sole fonio may suggest that fonio performs best in a competition-free environment [NWAMINI & al. 2020]. However, in fonio maize inter-crop, GHOSH & al. (2006) suggested a higher resource-use efficiency at optimal crop mixture.

Table 3 presents a maize height range of 176.80 cm in 2F:3M and 210.33 cm in 2F:1M combination systems, while the sole maize was 185.80 cm. A lower value of plant height was noted in 2F:3M than in sole crop, providing an opportunity for fonio to out-compete maize for resources. The result is in agreement with FU & al. (2023) that taller maize plants will intercept more light in inter-cropping than in monocropping. Sole maize recorded a significantly lower value of 1.74 ears/plant while the highest were in 1F:2M and 1F:3M (2.16 and 2.45ears/plant respectively), suggesting a better resource and reproductive outcomes [MEAD & WILLEY, 2008]. Higher number of ears in intercropping is therefore an indication of a positive interaction, meanwhile OFORI & STERN (1987) had hinted that some systems can enhance reproductive output between maize and fonio. The average number of rows per ear was 14.24, indicating that maize was seriously affected by the inter-crop, in which LI & al. (2020) viewed as due to stress from competition with a resource-demanding companion. Increase in the number of grains per row and number of grains per ear in 2F:2M combination system may lead to more efficient resource utilization because of a complementary effects. NWITE & al. (2017) made similar observation, where significant increase in grain set of maize in a maize legume inter-crop than in sole crop. The system with 75% fonio and 25% maize had significantly more grains per plant, suggesting improved access to resources [HASANVAND & al., 2019]. Meanwhile, reduction in 1000 grain weight and grain yield in some systems confirm that maize was stressed due to competition, which could reduce kernel size, seed weight and subsequent grain yield as reported by WILLEY (1979) and GHOSH & al. (2006). Exception on 3F:1M and 2F:1M combination systems, which shows relatively good yields of 3.11 t/ha and 3.10 t/ha respectively, suggesting that combining with fonio helps to optimize land use efficiency. The 1F:2M, 2F:1M, and 3F:1M inter-cropping systems are promising results for improved resource utilization. 2F:2M and 3F:2M systems allow for more efficient space and nutrient sharing, which could be useful in areas with limited arable land.

In Table 4, maize yields are generally lower in inter-crop than in sole maize system. FM (100:100) has a land equivalent ratio of 1.70, indicating a land-use advantage of 70%. 1F:1M has land equivalent ratio of 1.32, implying a 32% advantage in land productivity, while 3F:1M has 1.55, showing significant land-use efficiency when fonio constitutes 75% of the system. GHOSH & al. (2006) proposed that when Land Equivalent ratio is above 1, the inter-cropping can make more efficient use of land resources than monocropping. Relative crowding coefficient recorded below 1 values for fonio but closer to 1 for maize, showing that maize often has a higher competitive pressure on fonio than vice versa. In 3F:1M, Relative crowding coefficient were 0.57 and 2.22 for fonio and maize respectively. This is a reflection of stronger competition for resources by maize, signifying that fonio is a relatively low-competition crop but can be grown alongside other crops without significant yield loss. However, MEAD & WILLEY (2008) also recommended low competitive crop like fonio as suitable companion crop due to their ability to improve soil health, prevent erosion, and increase biodiversity. In combination where 33% is fonio, maize recorded higher aggressivity score of 2.29 and fonio recorded 0.465, suggesting stronger competition from maize. But in FM (100:100) combination system, fonio displays a higher aggressivity (3.71) than maize, suggesting that fonio is more adapted to the condition of the system. While maize tends to have a higher competitive advantage in most systems, adaptability assists fonio to thrive even under reduced resource availability [GHOSH & al. 2006]. Consequently, fonio had significant yield loss of -11.82 in FM 100:100 combination system, resulting in a slightly reduced yield advantage. In 2F:2M, the inter-cropping advantage is more balanced, resulting in a positive (+0.94) value in fonio. WILLEY (1979) noted that yield losses in intercrops are typical, but often compensated by total higher yields per unit of land. However, BROOKER (2015) also highlighted that Inter-cropping advantage (IA) is usually evident in drought-prone ecologies having unstable weather conditions where it provides food diversification and better resource utilization. 1F:1M and 2F:2M inter-cropping systems showed considerable monetary advantages due to higher fonio yields with extra revenue. Meanwhile, FM (100:100) combination shows a negative monetary advantage index, suggesting that farmers in that location may not benefit financially in adopting the system.

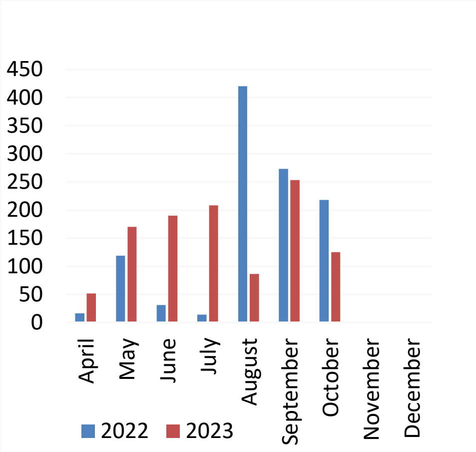

Figure 1. Rainfall pattern during the growing season at Badeggi

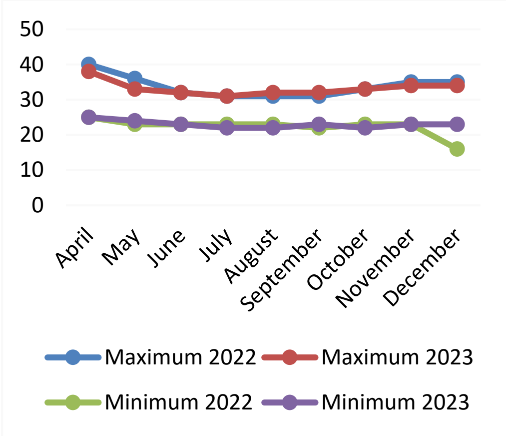

Figure 2. Temperature variation during the growing season at Badeggi

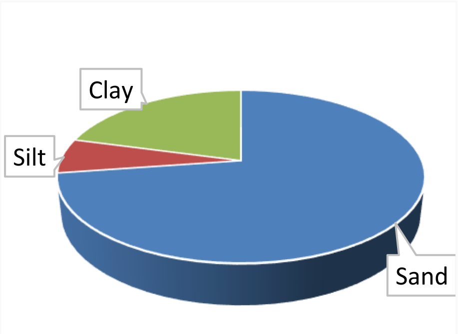

Figure 3a. Soil Physical property composition of experimental location in 2022 and 2023

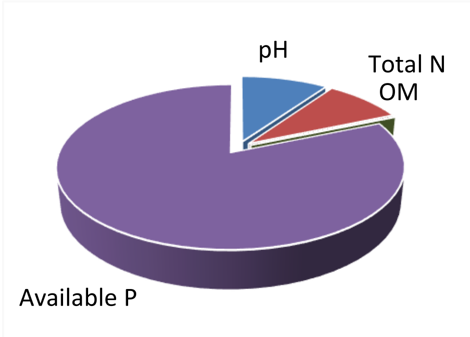

Figure 3b. Soil Chemical property composition of experimental location in 2022 and 2023

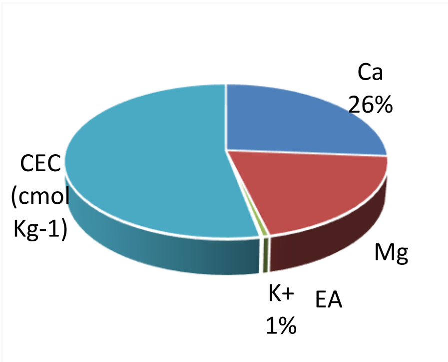

Figure 3c. Soil Exchangeable ions of experimental location in 2022 and 2023

Table 1. Intercropping arrangements in ten rows under rain-fed condition

Mix-Proportion (%)	Sole fonio	Sole Maize	Both crops grown mixed	1 alternate rows of fonio and maize	2 alternate rows of fonio, 1 of maize	2 alternate rows of fonio and maize	1 alternate rows of fonio, 2 of maize	1 alternate row of fonio, 3 of maize	3 alternate rows of fonio, 1 of maize	3 alternate rows of fonio, 2 of maize	2 alternate rows of fonio, 3 of maize
	100	100	100:100	50:50	67:33	50:50	33:67	25:75	75:25	60:40	40:60
Rows	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
1	ΔΔΔΔ	ψψψψ	ΔψΔψ	ΔΔΔΔΔ	ΔΔΔΔΔ	ΔΔΔΔΔ	ΔΔΔΔΔ	ΔΔΔΔΔ	ΔΔΔΔΔ	ΔΔΔΔΔ	ΔΔΔΔΔ
2	ΔΔΔΔ	ψψψψ	ψΔψΔ	ψψψψ	ΔΔΔΔΔ	ΔΔΔΔΔ	ψψψψ	ψψψψ	ΔΔΔΔΔ	ΔΔΔΔΔ	ΔΔΔΔΔ
3	ΔΔΔΔ	ψψψψ	ΔψΔψ	ΔΔΔΔΔ	ψψψψ	ψψψψ	ψψψψ	ψψψψ	ΔΔΔΔΔ	ΔΔΔΔΔ	ψψψψ
4	ΔΔΔΔ	ψψψψ	ψΔψΔ	ψψψψ	ΔΔΔΔΔ	ψψψψ	ΔΔΔΔΔ	ψψψψ	ψψψψ	ψψψψ	ψψψψ
5	ΔΔΔΔ	ψψψψ	ΔψΔψ	ΔΔΔΔΔ	ΔΔΔΔΔ	ΔΔΔΔΔ	ψψψψ	ΔΔΔΔΔ	ΔΔΔΔΔ	ψψψψ	ψψψψ
6	ΔΔΔΔ	ψψψψ	ψΔψΔ	ψψψψ	ψψψψ	ΔΔΔΔΔ	ψψψψ	ψψψψ	ΔΔΔΔΔ	ΔΔΔΔΔ	ΔΔΔΔΔ
7	ΔΔΔΔ	ψψψψ	ΔψΔψ	ΔΔΔΔΔ	ΔΔΔΔΔ	ψψψψ	ΔΔΔΔΔ	ψψψψ	ΔΔΔΔΔ	ΔΔΔΔΔ	ΔΔΔΔΔ
8	ΔΔΔΔ	ψψψψ	ψΔψΔ	ψψψψ	ΔΔΔΔΔ	ψψψψ	ψψψψ	ψψψψ	ψψψψ	ΔΔΔΔΔ	ψψψψ
9	ΔΔΔΔ	ψψψψ	ΔψΔψ	ΔΔΔΔΔ	ψψψψ	ΔΔΔΔΔ	ψψψψ	ΔΔΔΔΔ	ΔΔΔΔΔ	ψψψψ	ψψψψ
10	ΔΔΔΔ	ψψψψ	ψΔψΔ	ψψψψ		ΔΔΔΔΔ	ΔΔΔΔΔ		ΔΔΔΔΔ	ψψψψ	ψψψψ

Table 2. Performance of Fonio Parameters as affected by inter-cropping system

Planting pattern	Ratio (%)	DFF	NTPP	NPPP	PH (cm)	SL(cm)	PL (cm)
Sole Fonio	100	107.34^{bc}	22.00^{ef}	14.40^{de}	127.53^{cd}	14.00^{cd}	22.07^{d}
FM	100:100	109.67^{b}	26.67^{ab}	15.20^{d}	167.93^{a}	16.67^{a}	25.13^{a}
1F:1M	50:50	100.33^{cd}	23.27^{de}	20.60^{ab}	150.40^{b}	14.47^{bc}	23.67^{bc}
2F:1M	67:33	98.33^{d}	27.80^{a}	19.13^{bc}	120.20^{de}	15.07^{bc}	25.20^{a}
2F:2M	50:50	101.67^{bcd}	26.87^{ab}	20.53^{ab}	129.07^{c}	12.80e^{f}	21.53^{de}
1F:2M	33:67	100.67^{cd}	19.07^{g}	14.20^{de}	116.73^{ef}	12.00^{f}	20.40^{ef}
1F:3M	25:75	119.33^{a}	26.67^{ab}	13.00^{e}	109.47^{f}	10.40^{g}	20.20^{f}
3F:1M	75:25	120.33^{a}	24.67^{cd}	21.73^{a}	126.60^{cd}	12.13^{ef}	23.40^{c}
3F:2M	60:40	98.33^{d}	20.87^{fg}	18.33^{c}	113.07^{ef}	15.60^{ab}	24.87^{ab}
2F:3M	40:60	98.70^{cd}	25.27^{bc}	19.53^{bc}	147.47^{b}	13.27^{de}	23.40^{c}
Mean		105.47	24.32	17.67	130.85	13.64	22.99
Max		120.33	27.8	21.73	167.93	16.67	25.2
Min		98.33	19.07	13.00	109.47	10.4	20.2
SE		2.51	0.51	0.42	2.31	0.32	0.37
CV%		2.91	2.58	2.92	2.16	2.86	1.95
LSD5%		8.98	1.83	1.51	8.27	1.14	1.31

Table 2. (contd.)

Planting pattern	Ratio (%)	NSPP	DM	PW(g)	GY (kg/ha) 2022	2023	Mean
Sole Fonio	100	9.13^{a}	130.67^{e}	250.45^{b}	613.26^{a}	662.54^{a}	637.90^{a}
FM	100:100	8.73^{a}	150.67^{a}	212.42^{c}	481.49^{d}	521.98^{bc}	501.735^{cd}
1F:1M	50:50	7.13^{c}	145.33^{ab}	274.90^{a}	305.84^{f}	328.76^{e}	317.30^{f}
2F:1M	67:33	7.73^{b}	136.00^{cde}	185.52^{d}	403.86^{e}	503.12^{cd}	453.49^{e}
2F:2M	50:50	6.20^{d}	138.33b^{cde}	204.87^{c}	518.55^{c}	509.38^{cd}	513.965^{c}
1F:2M	33:67	7.40^{bc}	143.67^{abc}	216.86^{c}	488.27^{d}	474.53^{d}	481.4d^{e}
1F:3M	25:75	5.60^{e}	138.67^{bcd}	152.78^{e}	323.78^{f}	308.07^{e}	315.925^{f}
3F:1M	75:25	8.73^{a}	133.00^{de}	204.34^{c}	551.27^{b}	559.67^{b}	555.47^{b}
3F:2M	60:40	7.73^{b}	133.67^{de}	261.08^{ab}	509.56^{cd}	502.65^{cd}	506.105^{cd}
2F:3M	40:60	7.13^{c}	135.67^{de}	172.68^{d}	502.67^{cd}	521.67^{bc}	512.17^{c}
Mean		7.55	138.57	213.59	469.85	489.24	479.55
Max		9.13	150.67	274.9	613.26	662.54	637.90
Min		5.6	130.67	152.78	305.84	308.07	315.93
SE		0.13	2.15	4.41	7.93	10.74	8.43
CV%		2.03	1.90	2.53	2.07	2.69	2.15
LSD5%		0.45	7.72	15.82	28.42	38.49	30.22

DFF= Days to 50% flowering, NTPP = Number of tillers per plant, NPPP = Number of panicle per plant, PH = Plant height (cm), SP = Spike Length (cm), PL = Panicle Length (cm), NSPP = Number of Spikes per plant, DM = Days to maturity, GY = Grain yield (kg/ha). Local check – popular farmers' variety

Table 3. Performance of Maize Parameters as affected by inter-cropping system

Planting pattern	Ratio (%)	PH	NEP	NRE	NGR	NGE
Sole Maize	100	185.80^{c}	1.74^{f}	13.76^{cd}	40.76^{b}	726.51^{abcd}
ACMZ	100:100	188.53^{bc}	1.66^{f}	16.56^{a}	48.45^{a}	622.87^{f}
1F:1M	50:50	185.33^{c}	2.05b^{cd}	13.07^{d}	49.32^{a}	644.61^{ef}
2F:1M	67:33	210.33^{a}	2.02^{cd}	13.86^{cd}	48.34^{a}	699.99^{cd}
2F:2M	50:50	209.00^{a}	1.98^{de}	14.34^{bc}	50.65^{a}	766.32^{a}
1F:2M	33:67	201.73^{a}	2.16^{bc}	13.56^{cd}	50.05^{a}	728.68^{abc}
1F:3M	25:75	204.60^{a}	1.82^{ef}	15.04^{b}	47.87^{a}	749.97^{ab}
3F:1M	75:25	200.13^{ab}	2.45^{a}	14.24^{bc}	49.87^{a}	760.15^{ab}
3F:2M	60:40	184.53^{c}	1.98^{de}	13.77^{cd}	48.80^{a}	711.98^{bcd}
2F:3M	40:60	176.80^{c}	2.21^{b}	14.21^{bc}	47.76^{a}	678.67^{de}
Mean		194.68	2.01	14.24	48.19	708.98
Max		210.33	2.45	16.56	50.65	766.32
Min		176.80	1.66	13.07	40.76	622.87
SE		3.46	0.049	0.248	1.14	13.78
CV%		2.18	3.02	2.14	2.9	2.38
LSD5%		12.41	0.177	0.89	4.086	49.42

Table 3. (contd.)

Planting pattern	Ratio (%)	NGP	1000GW (g)	GY(t/ha) 2022	2023	Mean
Sole Maize	100	1264.13^{f}	315.44^{c}	4.62^{a}	4.62^{a}	4.62^{a}
ACMZ	100:100	1033.96^{g}	247.38^{e}	4.21^{b}	4.18^{b}	4.20^{b}
1F:1M	50:50	1321.45^{ef}	380.26^{b}	3.74^{c}	3.76^{cd}	3.75^{c}
2F:1M	67:33	1413.98^{cde}	305.87^{cd}	3.00^{f}	3.20^{e}	3.10^{e}
2F:2M	50:50	1517.31^{bc}	488.67^{a}	3.03^{ef}	3.00^{e}	3.02^{e}
1F:2M	33:67	1573.95^{b}	279.78^{d}	3.48^{d}	3.98^{bc}	3.73^{c}
1F:3M	25:75	1364.95^{def}	300.65^{cd}	3.66^{cd}	3.64^{d}	3.65^{c}
3F:1M	75:25	1862.37^{a}	308.67^{c}	3.00^{f}	3.21^{e}	3.11^{e}
3F:2M	60:40	1409.72^{cde}	302.76^{cd}	2.74^{g}	2.63^{f}	2.69^{f}
2F:3M	40:60	1499.86^{bcd}	290.56^{cd}	3.24^{e}	3.55^{d}	3.40^{d}
Mean		1426.17	322.0	3.47	3.58	3.53
Max		1862.37	488.67	4.62	4.62	4.62
Min		1033.96	247.38	2.74	2.63	2.69
SE		38.30	7.33	0.063	0.095	0.064
CV%		3.29	2.79	2.21	3.24	2.23
LSD5%		137.32	26.29	0.23	0.34	0.23

N/B: F = Fonio; M = Maize; NRE: number of rows per ear: NGR: number of grains per row; NEP: number of ears per plant; NGE: number of grains per ear; NGP: Number of Grains per plant; HSW: hundred grain weight; GY: grain yield

Table 4. Competition Indices in Sole stand and Inter-cropping System

Planting pattern	mix (%)	GY (ton/ha) Fonio	Maize	Total	Value (N/ha) Fonio	maize	total	LER Fonio	Maize	LER
Sole Fonio	100	0.64		0.64	513		513			
Sole maize	100		4.62	4.62		1386	1386			
FM	100:100	0.5	4.20	4.70	404	1257	1661	0.79	0.91	1.70
1F:1M	50:50	0.32	3.75	4.07	258	1126	1384	0.51	0.81	1.32
2F:1M	67:33	0.45	3.10	3.55	370	940	1310	0.71	0.67	1.38
2F:2M	50:50	0.52	3.02	3.53	411	903	1314	0.81	0.66	1.47
1F:2M	33:67	0.48	3.73	4.21	382	1144	1526	0.76	0.81	1.56
1F:3M	25:75	0.31	3.65	3.96	246	1094	1340	0.49	0.79	1.29
3F:1M	75:25	0.56	3.11	3.66	445	942	1387	0.88	0.68	1.55
3F:2M	60:40	0.505	2.69	3.19	403	800	1203	0.8	0.58	1.38
2F:3M	40:60	0.51	3.40	3.91	410	1034	1444	0.8	0.74	1.54

Table 4. (contd.)

Planting pattern	mix (%)	RCC Fonio	RCC Maize	RCC	CR Fonio	CR Maize	AGG Fonio	AGG Maize
Sole Fonio	100	1.0		1.00				
Sole maize	100		1.0	1.00				
FM	100:100	3.71	9.89	36.62	0.87	1.15	-11.82	11.545
1F:1M	50:50	1.02	4.31	4.39	0.625	1.605	-15.655	15.11
2F:1M	67:33	1.24	4.17	5.28	0.375	2.23	22.755	-22.795
2F:2M	50:50	4.59	1.88	8.65	1.24	0.81	9.955	-9.94
1F:2M	33:67	6.66	2.28	13.88	2.29	0.465	-23.175	1.87
1F:3M	25:75	2.91	1.26	3.65	2.1	0.52	-46.06	45.655
3F:1M	75:25	2.47	6.19	14.89	0.57	2.22	50.71	-51.205
3F:2M	60:40	2.74	2.09	5.81	0.97	1.275	26.205	-24.83
2F:3M	40:60	6.20	1.89	11.36	1.74	0.52	-9.655	9.235

Table 4. (contd.)

Planting pattern	mix (%)	AYL Fonio	AYL Maize	AYL Total	IA Fonio	IA Maize	IA Total	MAI
Sole Fonio	100							
Sole maize	100							
FM	100:100	-0.21	-0.09	-0.31	-126	-18.5	-144.5	683.94
1F:1M	50:50	0.02	0.63	0.64	12	125	137	330.21
2F:1M	67:33	-0.10	1.03	1.08	-60	206.9	146.9	375.60
2F:2M	50:50	0.63	0.30	0.94	378	60.9	438.9	407.91
1F:2M	33:67	1.30	0.21	1.51	780	41	821	549.96
1F:3M	25:75	0.96	0.06	1.02	576	11.1	587.1	287.60
3F:1M	75:25	0.17	1.69	1.86	99	337.9	436.9	492.16
3F:2M	60:40	0.33	0.45	0.78	195	90	285	320.94
2F:3M	40:60	1.01	0.17	1.18	606	33.4	639.4	506.35

N/B: GY = Grain yield (kg/ha), LER= Land equivalent ratio, RCC = Relative crowding coefficient (K), CR = competitive ratio, AGG = Aggressivity, AYL = Actual yield loss, IA = inter-cropping advantage, MAI = Monetary Advantage Index

Conclusions

Inter-cropping systems involving fonio and maize generally provide higher land productivity, greater resource efficiency, and economic benefits through increased yield and crop diversification. Although fonio performs best in a sole cropping system, FM 100:100 system seems particularly beneficial for both crops, suggesting that maize and fonio can complement each other when planted in equal proportions. Furthermore, the 1F:3M combination system, with a lower proportion of fonio, results in reduced performance of fonio due to domination from maize. Systems with a higher proportion of maize tends to delay flowering, reduce plant height, and negatively affects yield of fonio. Relative crowding coefficient values were below 1 for fonio but closer to 1 for maize, showing that maize often have higher competitive pressure on fonio than vice versa. Selecting early maturing fonio varieties can reduce the competition with maize and allow for better resource allocation. However, adaptability assists fonio to thrive even under reduced resource availability. Systems like 1F:2M and 2F:2M, constituting about 50-75% maize, should be promoted to farmers in regions where water scarcity is a concern. These systems could potentially balance the crop yield while optimizing space, nutrition and water usage. Farmers in rainfed areas are encouraged to adopt inter-cropping systems, particularly those with a balanced ratio of fonio and maize, which help ensure food security and increased resilience to climate variability. Research on inter-cropping has shown that optimal crop mixture often leads to higher resource use efficiency compared to monoculture. However, further research regarding combination systems with positive monetary advantage index should be extended to other fonio growing ecologies, with particular focus on improved adoption and economic impacts of the intercropping systems.

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