

Growth Analysis, and Yield Responses of Millet (*Pennisetum glaucum* (L.) R. Br.) and Cowpea (*Vigna unguiculata* [L.] Walp) in an Intercropping System

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Abstract: Niger, with a diversified agricultural production system, is dominated by the cultivation of millet for cereals, and cowpea for legumes where they are most often grown in combination. Among the cereal/legume combinations observed, the millet/cowpea combination is by far the most used by producers. This study aimed to evaluate the field experiment in 2021 rainy conditions, the growth, and the yield and yield components of millet/cowpea intercropping. A split-plot design was employed in this experiment, with treatments in main plots, and the varieties in small plots. Treatments included millet sole crop, cowpea sole crop, and intercropping millet/cowpea. Three genotypes of cowpea and a variety of millet, Heini Kirey Précoce (HKP) were used in this study. Growth and yield variables such as leaf area index (LAI), specific leaf area (SLA) and crop growth rate (CGR), biomass and seeds yield, millet 1000 seeds weight, harvest index, and LER were determined. Four cuts were made to determine the growth variables, at the tillering stage, elongation stage, 50% flowering of millet, and dough stage of millet grains. The results showed that total dry matter achieved by intercrop was significantly higher than those achieved by either millet or cowpea sole crop. Grain yield and thousand grain weights of millet were not affected by intercropping while cowpea did not produce any grain. The LAI was higher in intercropping than in sole crops, with higher values at the dough stage of the grains. The growth was maximal for both crops between the second and third cut with optimal growth rates. The LAI was higher in association than in pure culture and with higher values at the dough stage of the grains. Growth was maximum between the bolting and 50% flowering stages with optimal LAI and growth rate values.

Keywords: Dry Matter, LAI, Legume, Cereal, Niger

1. Introduction

In Niger, millet [*Pennisetum glaucum* (L.) R. Br.], the main staple food, dominates agricultural production systems and contributes about 75% to national cereal production [1]. It is grown to over 7.3 million hectares in Niger, i.e. 17% of Africa and Asia with a production of 3.862.155 tons [2]. Millet is mainly grown for its grains and its fodder [3-6]. Cowpea (*Vigna unguiculata* (L.) Walp) is the second most cultivated crop species after millet. It is the main source of protein for rural populations [7]. This legume is present in all

the sahelian countries, where it is cultivated in sole crop or, most often in association with cereals, particularly millet, and sorghum. According to FAO, the consumption patterns in the sahel are based on cereals, which provide approximately 65% of calories and 61% of proteins [8].

Indeed, one of the major challenges facing humanity is that of environmental degradation and its corollaries, as well as the problems of climate change. In Niger, agriculture, which is the engine of economic growth [9], remains the sector most directly threatened by these changes. Demographic pressure is also leading to increasingly intensive exploitation

of natural resources (land, pasture), resulting in lower yields [10]. In addition to this demographic pressure, there is also drought, which is one of the major causes of the drop in agricultural production in rain-fed agriculture in the tropics [11]. The low level of fertility of these soils requires recovery to improve agricultural yields.

To overcome these problems, one of the options is the association of cereals and legumes by combining micro fertilization [12]. In Niger, the most widespread cropping system is the millet-cowpea association, which employs 67 to 87% of farmers depending on the region [13, 14]. The performance of this cropping system is largely explained by the complementarity between the cereal and the legume for the use of nutrients and light because cereals only use nitrogen from the soil whereas protein crops mainly use nitrogen from the air (symbiotic fixation) when they are associated (88% of the nitrogen sampled according to [15]. This complementarity translates almost systematically into a significant improvement in the protein content of the cereal [16-19]. Crop associations would also make it possible to reduce the pressure of bio-aggressors (diseases, weeds, and pests) compared to that exerted on pure crops which is a major issue in organic farming where biotic factors can induce significant yield losses [20-22]. Thus, legumes play a triple role in protecting soil against degradation, controlling weeds, and improving and maintaining soil fertility by fixing atmospheric nitrogen. Therefore, their insertion in cropping systems with cereals is one of the approaches that lead to an improvement in crop productivity [23, 24].

However, plant surfaces are often characterized by biophysical parameters such as leaf area index (LAI), plant cover fraction, or chlorophyll concentration. These variables control and are controlled by the main processes involved in the functioning of the plant. Among these variables, the LAI, defined as the total area of foliage per m² of soil, is a key variable because it is involved in many processes such as radiation interception, photosynthesis, and evapotranspiration [25]. The LAI, therefore, conditions the exchanges of carbon and water fluxes with the atmosphere. Having access to precise estimates of the LAI on many types of plant cover is therefore essential for a large part of the scientific community, and therefore constitutes a major problem [26].

Thus, the production of biomass in crops is a function of the amount of radiation intercepted by the canopy, the importance and distribution of the leaf surface (position and orientation of the leaves), and the conversion efficiency of this radiation in dry matter [27, 28]. Therefore, the relationship between leaf area index (LAI) and dry matter productivity is obvious. This study aimed to evaluate in-field experiments, the growth, and the yield and yield components of millet/cowpea intercropping.

2. Material and Method

2.1. Study Site

The experiment was conducted in the field on the

experiment site of the Faculty of Science and Technology of Abdou Moumouni University in Niamey during the 2021 rainy season.

This site is located between 13°30' North latitude and 2°05' East longitude with an altitude of 204 meters. This site is located in the south-western Sahelian biogeographical compartment characterized by a rainfall index (PI) equal to 400 mm < PI > 600 mm, a relative humidity (RH) of 20% (February) < RH > 73.5% (August), a temperature (T) of 24°35 (January) < T > 33°64 (April) and a thermal amplitude of 9°29. The soil is of the leached tropical ferruginous type with a sandy texture. Table 1 gives the initial physicochemical characteristics of the soil of the study site. The average precipitation from 2011 to 2021 was 535.71 mm. During the test, the cumulative rainfall was 436.7 mm. Figure 1 gives the monthly rainfall distributions for the trial period.

Table 1. Initial physicochemical characteristics of the site's soil.

Parameters	Values
N-total (mg/kg)	152,8
C. Org (%)	0,11
P-Bray1 (mg/kg)	31,8
pH/H ₂ O (1: 2.5)	6,4
pH/KCl (1: 2.5)	6,0
Sand (%)	66,5
Silt (%)	29,2
Clay (%)	1,8

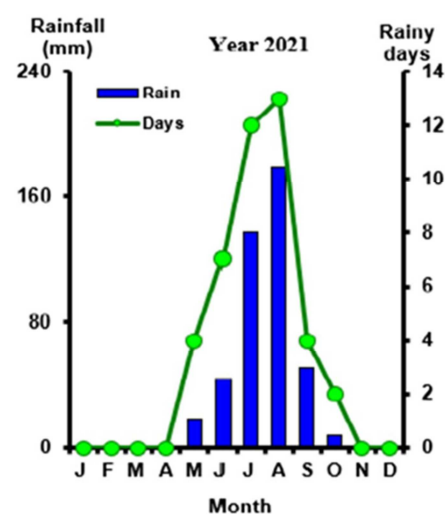


Figure 1. Monthly precipitation distributions for the year 2021 at the study site.

Conduct of the trial

The soil preparation work consisted first of all in a complete plowing of the field using a plow at a depth of 20 cm, then followed by staking out the plots to delimit the plots. The experimental design used is a split plot. Treatments (intercropping and sole crop) in main plots and varieties in elementary plots. Treatments are sole cowpea, sole millet, and intercropping millet/cowpea. The main plots are spaced 2 m apart and the elementary plots are 1 m apart. Each elementary plot has an area of 5.4 m² (2.4 m × 2.25 m). The spacings for millet were 80 cm between pockets and 75 cm between rows. For cowpea, the spacing between pockets was

30 cm and 50 cm between rows.

The same spacings were kept in the pure culture of millet and association with cowpea.

Three cowpea varieties (V1: CWS-F6-38-52, V2: CWS-F6-38-36, V3: CWS-F6-38-34) and one HKP (Hayni Kirey Early) millet variety with an average cycle 90 days were used in this study. The choice of varieties is based on their dual use: The production of seed and fodder. Sowing was done manually and simultaneously for millet and cowpea using dabas on June 22, 2021. A pinch of a few grains of millet was put in the pockets to ensure their germination and 4 seeds of cowpea per hill. We had spread 15,000.6 kg/ha or 1.56 kg/m² of manure and a supply of 60 kg/ha of NPK (15-15-15) in the form of a microdose at sowing, i.e., 3.6 g/hill. A few days after emergence, a re-sowing was done for the pockets with a low germination rate, then we thinned out on the 15th day after sowing to 2 plants per pocket for the cowpea and 3 plants for the millet then one (1) foot for each on the 21st day after sowing. Manual weeding was carried out throughout the duration of the trial to avoid competition from weeds.

2.2. Collection of Data

4 samples (sections) were taken during this trial.

The first sample was taken at the tillering stage, on July 22, i.e., 30 days after sowing (30 DAS); the second sampling took place at the rising stage of the millet on August 12 around 50DAS; as for the third sampling, it was carried out at 65DAS around August 27 at the time of 50% flowering of millet and finally the fourth sampling was done on September 13 (80DAS) at the pasty stage of millet grains. The method used is the same for all samples. It consisted of the association and the pure culture in a random sampling of the data on a square of yield of 1.6 m² (0.8m*0.75m) formed of 4 plants of millet and 4 plants of cowpea. This is obtained by destructive cutting of the millet and cowpea plants, the cutting of the plants is done at the collar and then the stems and the leaves are separated. The leaves are then put in aluminum foil and then in transparent bags to prevent their dehydration. The samples are then transported to the laboratory for various measurements.

2.3. Measurements and Observations

The dates of emergence, the beginning of millet tillering, flowering, heading, and 50% flowering were observed.

2.3.1. Leaf Area Measurement and Leaf Index (LAI) Calculation

The leaf surface constitutes the main part of the transpiring surface of the plant. The leaf area associated with the surface of the soil covered by the plant is often used to measure the leaf area index (LAI) which makes it possible to describe the interception of radiation, soil temperature, transpiration, and plant productivity.

In this work, the leaf area of millet was determined by measuring the dimensions (length and width) of the leaf. As a result, the shape of the leaf has been described by analytical expressions linking length and width (arcs of a parabola: [29,

30] arcs of sinusoids: [31, 32] which by integration make it possible to calculate their surface, for millet we had used the coefficient of 0.75. The measurement of the dimensions consisted of measuring:

1. The length of the leaf (L in cm) from the ligule to the tip of the leaf;
2. And the greatest width (l in cm)

The leaf area is thus calculated by the product of the length and the maximum width and the coefficient of 0.75 representing the shape of the leaf.

To obtain the LAI, the leaf area is divided by the area of the ground occupied by the plant (0.75m*0.8m).

$$LAI = \frac{\sum L * l * 0,75}{(0,75 * 0,8)}$$

The cowpea leaf area was determined using image processing software called "Image J" [33]. The method consisted in measuring the surface of the leaves using a scanner, the leaflets of the detached leaves are placed, without touching each other, on a white background and then scanned in black and white. The image is then processed with the "ImageJ" digital imaging software which, after binary conversion of the image, identifies objects and calculates their surface area in pixels. A simple conversion from the resolution of the scanned image (pixels/inches) makes it possible to know the leaf area of a leaf. The overall leaf area of the sample (composed of 4 plants) is then obtained by summing all the leaf areas of the plants comprising the sample. To obtain the LAI, we first calculated the leaf-specific weight (SLW) by dividing the leaf dry biomass (TDB) by the leaf area (LA). Thus the LAI is calculated as follows:

$$LAI = \frac{TDB}{SLW * \text{area occupied by the plant}}$$

TDB: total dry biomass;

SLW: Specific Leaf Weight.

For the intercropping, the LAI of millet and cowpea were measured separately, and the LAI of the association was obtained by the average of the LAI of millet and cowpea [34].

2.3.2. Determination of Grain Yield and 1000 Grain Weight of Millet

At maturity, a full data collection (millet, cowpea, and millet grain biomass) was carried out on each elementary plot. After harvest, the cobs and the biomass (stem and leaves) are separated and then dried in the shade to a constant weight before being weighed. For the weight of the 1000 grains, an automatic counting device named MUNIGRAL was used, to obtain the thousand grains for each plot. Thousand-grain weight was measured using a 10-3 precision Sartorius balance.

2.3.3. Analysis of Growth Over Time

The first analyses of growth were carried out as a function of time [35]. Accordingly, the classical approach described growth as a change in biomass over time (t). The crop growth rate (CGR) was easily estimated from successive harvests during the season. It measures the plant's efficiency in producing new material, i.e. the amount of plant material

growing per unit of dry weight [36]. The following formula is used to calculate it: $CRG = \frac{W_2 - W_1}{SP(t_2 - t_1)}$ (g. m⁻². day⁻¹), where W1 and W2 are dry weights at times t1 and t2 (time between two cuts).

3. Statistical Analysis

The data collected was entered into an Excel 2013 spreadsheet and subjected to an analysis of variance (ANOVA) on Minitab 16 software after checking the normality of the data by the Ryan Joiner test. The graphs and tables were made on Excel 2013 and the comparison of the means was done by the Tukey test at the 5% threshold.

4. Results

4.1. Effect of Intercropping on Cowpea Phenology

The flowering start date in cowpea varieties was significantly affected in combination (P=0.009). However, the sole crop had no significant difference (P = 0.977). The flowers appeared on average at 54 DAS in intercropping and 46 DAS in the sole crop. In both cultural practices, varieties 1 and 3 were the earliest while variety 2 was the latest. It should be noted that the cowpea has started to flower, but the flowers that appeared have all aborted, and new flowers have not appeared. Therefore, the cowpea did not give pods.

Table 2. Cowpea flowering start date.

Varieties	Intercropping	Sole crop
V1	48ab	45a
V2	61b	48a
V3	5c	45a
P-value	0,009 **	0,977 ns

**, =significant at the probability threshold of 0.05; ns = not significant. Figures with the same letter (s) in the same column are not significantly different at the 0.05 level

4.2. Effect of Intercropping on Cowpea Haulm Yield

The results indicate that there is no significant effect of cowpea varieties on haulm yields in intercropping. The test was significant only in the sole crop. Indeed, the best haulm

yield observed in the sole crop was recorded by variety 2 (V2=5888.9 Kg/ha), and the lowest by variety 3 (V3=4660.5 Kg/ha). At the level of the association, the best yield was recorded by variety 1 (V1=4824.1 Kg/ha) and the smallest by variety 2 with an average of 3537.0 Kg/ha.

The ANOVA test reveals a significant difference between the two culture methods (P=0.002) (Table 3). Overall, cowpea haulm production was higher in the single crop than in intercrop.

Table 3. Cowpea haulm yield.

Varieties	Intercropping	Sole crop
V1	4824,1 ± 720,2 a	5002,5 ± 535,9 ab
V2	3537,0 ± 204,8 a	5888,9 ± 111,1 a
V3	3824,1 ± 405,9 a	4660,5 ± 287,1 c
P-value	0,144 ns	0,009**
Mean	4061,7 ± 709,9 a	5450,6±669,3 b
P-value	0,002 **	

**, =significant at the probability threshold of 0.05; ns = not significant. Figures with the same letter (s) in the same column are not significantly different at the 0.05 level.

4.3. Effect of Intercropping on Millet Yield

Table 4 shows us the variations in millet yields in intercropping and sole crops, so the results indicate that the biomass and grain yields of millet were not significantly influenced by the cultural practice. However, millet biomass and grain yields were higher in sole crops than in intercropping with cowpea. The differences between the sole crop and the intercropping for biomass and grain yield were 7.58% and 16.91% respectively. The ANOVA test also revealed no significant difference in 1000 grains weight and harvest index between the intercropping and the sole crop. Regarding the weight of 1000 grains, the greatest weight is recorded in association with variety 2 (V2=14.47g). The millet in sole crop and intercropping with Variety 1 recorded approximate values of 13.55g and 13.54g respectively. Variety 3 has the smallest weight (13.28).

There is not a very big difference between the two types of crop for the harvest index (HI). Thus, the best HI is observed by millet sole crop (0.270) and the lowest by millet intercropped to variety 2 (0.196).

Table 4. Variation in yields of millet in sole crop and intercropping system.

Varieties	Grains yield (Kg/ha)	1000 grains weight (g)	Dry matter yield (kg/ha)	HI
V1/Millet intercropping	1530,7300 a	13,5400 a	6654,3167 a	0,230 a
V2/Millet intercropping	1406,3933 a	14,4733 a	7271,5967 a	0,196 a
V3/Millet intercropping	1644,5933 a	13,2833 a	6567,8967 a	0,268 a
Sole Millet	2147,9967 a	13,5567 a	7950,6133 a	0,270 a
P-value	0,87 ns	0,279 ns	0,427 ns	0,276 ns

ns = not significant at the probability threshold of 0.05 Figures with the same letter (s) in the same column are not significantly different at the threshold of 0.05.

4.4. Effect of Intercropping on the Growth of Millet

4.4.1. Evolution of the LAI

The ANOVA test did not reveal any significant difference

between the varieties at the cut level.

The LAI values evolve until cut 3, at cut 4 there is a drop, whether in intercropping or sole crops (figure 2 and Figure 3). The LAI values of the associations are higher than those of the sole crops for each cut.

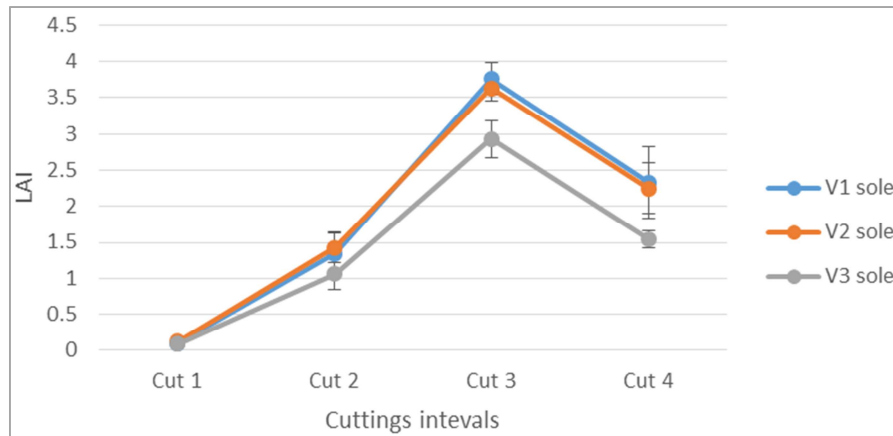


Figure 2. LAI of sole crops of cowpea.

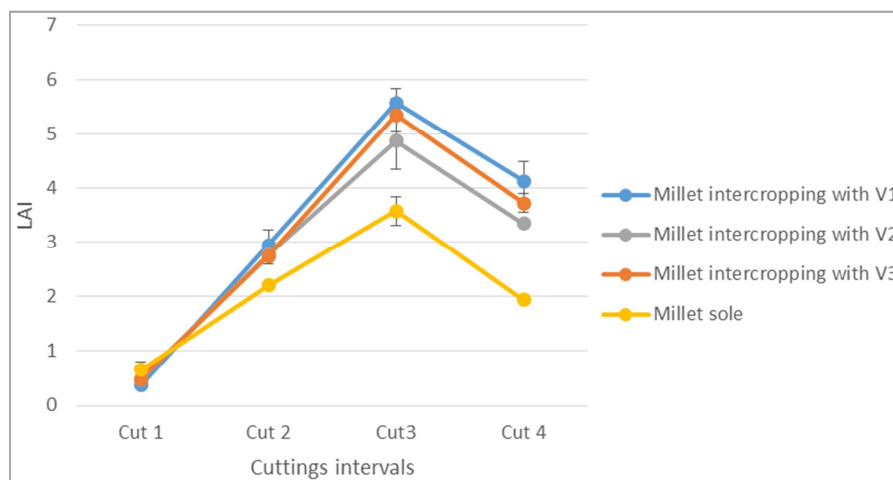


Figure 3. LAI of millet/cowpea intercropping and sole millet.

4.4.2. Rate of Growth

The analysis of variance reveals no significant difference between varieties for all cuts. For millet as well as for cowpea, growth is accelerated from cut 1 to cut 3 and then slowly decreases over time (cut 4) (Figures 4, 5).

Indeed, millet in the sole crop shows the highest growth

(25.5) against 23.15 in association with variety (1) and varieties 2 and 3 with approximate values of 21.32 and 20.53 respectively. The growth of millet in association with all varieties of cowpea is accelerated up to cut 3 and then decreases in cut 4. The CGR of cowpea was reduced in intercropping with millet compare to sole crop (Figure 5).

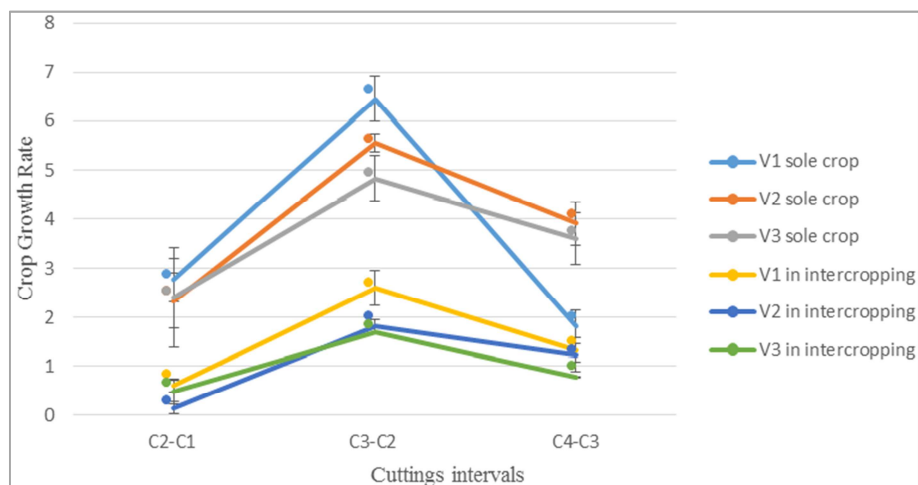


Figure 4. The growth rate of cowpea in sole crop and intercrop.

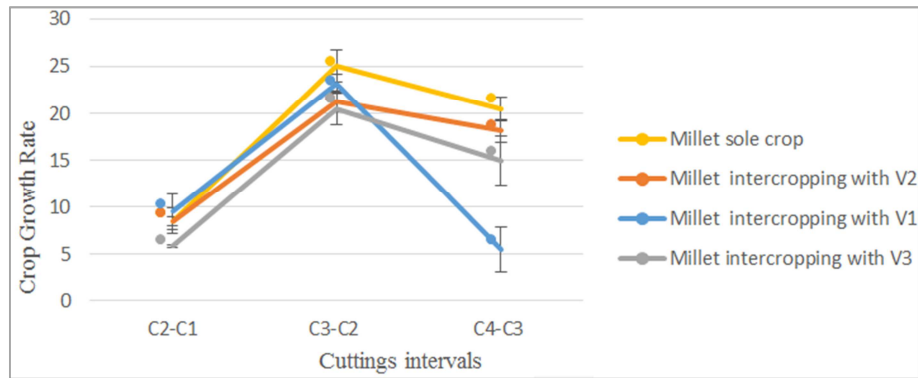


Figure 5. The growth rate of millet in sole crop and intercropping with cowpea.

5. Discussion

5.1. Phenology

The flowering date of these varieties was between the 48th and 61st day after sowing. After the appearance of the first flowers, these were aborted a few days later and there was no appearance of new flowers. Indeed, the varieties developed a lot of biomass to the detriment of the formation of flowers. The virtual absence of flowering in these varieties cannot be explained by the fact that these varieties are preferred photoperiods, that is to say, they need short days to flower but can flower weakly even when the day length exceeds the critical photoperiod. This could be explained in the context of our study by the "early" sowing carried out in June which coincided with long days exceeding an average of 12.5 hours in July and 12.40 in August, months which corresponded to the flowering period of these varieties. The difference in flowering days could be due to varietal character, sowing time, and growing environment [37]. Many species need to be exposed to specific photoperiods and/or temperatures to flower [38]. These two parameters mainly control the phenology of the majority of annual legumes, including cowpea [39]. There was no significant difference in pure culture, on the other hand, we note that varieties 1 and 3 flowered faster than variety 2 (as well as in association).

5.2. Yield and Yield Components

For total yields (millet and cowpea), the association produced much more biomass. However, there is a slight advantage of the pure culture compared to the references of each species in the association. Researchers showed that in terms of straw and haulm production, intercropping significantly reduces the yield of each component compared to its sole crop ($p < 0.05$) [40]. In the context of our work, intercropping did not significantly reduce the biomass yields of millet and cowpea. Growing two or more crops in the same plot often results in reduced yields of both crops due to competition for limited critical environmental resources [41-43]. This drop in biomass yield in association with the case of our results could be due to competition between the two

crops in association in terms of nutrients due to high densities, which did not allow good vegetative growth and therefore good biomass production. But, in terms of nutritional quality, the introduction of cowpea in the millet cultivation system qualitatively improves production by increasing those lipids and proteins on the same surface. This is confirmed by some works, which showed that the peanut-maize crop association significantly improves the production of proteins (24.1% to 106.2%) and lipids (147.9% to 386%) [44]. Indeed, in addition to its character of grain quality improvement, cowpea as a food legume plays a role of complementarity with the cereal in the diet [45]. In the same climatic zone, the sorghum-cowpea association reduces soil erosion by 80% compared to the pure culture of sorghum and by 45 to 55% compared to that of cowpea [46]. All this could explain the widespread practice of this culture in the regions.

The same trend was observed in the grain yield of millet, with a slight advantage for the pure culture of millet. The drop in grain yields recorded in the millet system in association with cowpea compared to the pure millet system could be explained by the competition between cowpea and millet for moisture and nutrients. But also, by simultaneous sowing. Thus, the best strategy to reduce the dominance of millet and optimize the productivity of cowpea is to sow the two crops simultaneously [47]. As the experiment was conducted for a single year, the results obtained did not highlight a positive influence of the association with cowpea on the grain yield of millet.

The harvest index was not significantly affected by the cultivation methods ($p = 0.276$), it is generally higher in pure culture than in association because of the high biomass production. The weight of 1000 grains of the millet-cowpea association is 1% higher than that of millet grown in pure form. The difference is not significant in the two types of cultures. [48] also found no effect of the association on the 1000-seed weight of the bean.

5.3. Effect of the Association on the Growth of Millet and Cowpea

The average LAI values are higher in the associated cultures than in the pure cultures for the different cuts made. Explaining, in particular, a good soil cover by millet and cowpea in association. Indeed, the size of the plant, the shape

of the stem, and the leaves (thin or thick) can be important factors for the penetration of light into the canopy, which will eventually lead to a low or high LAI value. In our study, the cowpea varieties are creeping with much wider leaves and stems which allows good light interception and therefore a better LAI. This illustrates the evolution of LAI by increasing the number of leaves and subsequently increasing the height according to [49]. The temporal evolution of the occupation of the fraction of the vegetation cover and the LAI are similar as shown by [50]. That is to say that the more the plants grow, the more space they will have. Therefore, this will contribute to increasing the value of LAI. The growth rate results showed that in cowpea, there are three main phases of growth. The first phase is during the first 30 days after sowing (JAS) which corresponds in our study to cut 1, it is characterized by a slow growth of the plants. In this same phase, plants accumulate significant amounts of water in their tissues. These physiological growth phenomena were also observed by [51]. The second phase also lasts 30 days for some varieties and can extend up to 45 days for others (section 2). This is the actual growth phase: it presents a very rapid acceleration of the growth of the plants. Thus, in cowpea, most of the water needs would be met during the first 30 days of the cycle. This would undoubtedly explain its great ability to adapt to low rainfall areas. Following a study on cowpea in a semi-arid zone similar results were obtained [52]. In the third phase, which is after the 60th day (section 3), cowpea growth generally becomes much slower and then stops around the 75th DAS (section 4). The slowdown, followed a few days later by the cessation of growth beyond 75 days in the varieties, could be attributed to the phenomenon of senescence. Indeed, during this period, there would be an increased production of a hormone in the form of abscisic acid which promotes aging and leaf fall following a stoppage of the supply of water, mineral, and carbon elements to the level of the different organs of the plant [53]. The appearance of these signs often marks the end of a growth cycle in annual plants [11].

6. Conclusion

Our study was carried out to estimate the growth and yield of millet in sole crop and intercropping. Therefore, the results obtained on the seed yields and total dry biomass of millet and cowpea showed that the yields in intercropping and sole crop of millet are not statistically significant. The difference was observed in cowpea haulm yield between the two types of crop, where it is also higher in the sole crop. This allows us to conclude that the insertion of cowpea did not have a positive effect on the production (biomass, seeds) of the cultivation of millet in combination with millet and cowpea compared to its sole crops.

The combination of two crops allows growers to better manage growing space (increasingly scarce) while producing benefits in terms of weed control, ground cover, soil protection against erosion, and dispersal of insects.

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