International Journal of Agriculture and Forestry 2020, 10(3): 76-83
DOI: 10.5923/j.ijaf.20201003.03

Exploring the Effect of Monocropping, Intercropping and Fertilizer Use in Maize (*Zea mays* L.) Production in Central Mozambique

Miquitaio D.[1,2,3], Miguel A. M.[4], Simbe J.[4], Oliveira M. M.[2], Abreu I.[2,*]

[1]Universidade Púnguè, C.P. 323, Bairro Heróis Moçambicanos, Chimoio, Moçambique
[2]Universidade Nova de Lisboa, Instituto de Tecnologia Química e Biológica António Xavier (ITQB NOVA), Avenida da República Oeiras, Portugal
[3]Graduate Program for Science and Development (PGCD), Instituto Gulbenkian de Ciência, Rua da Quinta Grande, Oeiras, Portugal
[4]Instituto de Investigação Agrária de Moçambique (IIAM), Centro Zonal Centro, C.P. 42, Rua Pigivide 678, Chimoio, Moçambique

Abstract Maize (*Zea mays* L.) is the most important cereal in Mozambique. However, its productivity is low due to several constraints, including drought, low soil fertility, pests and diseases. The present study aimed at analyzing two cropping systems, namely, monocropping and intercropping, and delivering knowledge to improve maize production in Central Mozambique. Two locations were selected for the experiments, Sussundenga and Rotanda Agronomic Stations. We tested the agronomic performance of three open-pollinated maize varieties, Matuba, ZM309, and ZM523, in rainfed conditions in 2017/2018 and 2018/2019 cropping seasons. The treatments analyzed in the first season were the maize varieties grown as monoculture and maize intercropped with cowpea *Vigna unguiculata* (L.) Walp, both without any use of inorganic fertilizers. In Sussundenga, monocropping yielded 2410.4 to 3033.5 kg/ha of maize grain, while in intercropping, the yield was lower, ranging from 961.9 to 1282.9 kg/ha. However, the yield was more comparable between treatments in Rotanda, where monocropping yielded 1996.2 to 2310.7 kg/ha while for intercropping, 1478.3 to 2033.6 kg/ha was obtained. In the second season, we added fertilizer impact as an extra variable and in general contributed to increase 1.5 to 2.6 times grain yield over de non-fertilized plots. Additionally, we introduced relay intercropping to reduce competition between maize and cowpea, and obtained 2897.7 to 3958.4 kg/ha in Sussundenga, and 2613.8 to 3099.8 kg/ha in Rotanda. Overall, our data suggested that under sufficient rainfall, the tested varieties performed similarly. Also, although it should be optimized to fit the actual agro-ecological conditions, intercropping can be considered as a good strategy to increase yield, especially when combined with the use of fertilizer.

Keywords Agronomic performance, Monocropping, Intercropping, Fertilizer, Mozambican maize

1. Introduction

Maize is the most important cereal crop in Mozambique [1]. Most of the farmers produce maize exclusively for the household needs, with a little surplus to sell in the local market [2-4]. Maize production is low and currently estimated to be around 0.3 - 0.9 t/ha, which is far from its actual potential productivity (about 6t/ha if using improved farming practices). The average yield of Africa's southern region, which includes Mozambique, is about 4.9 t/ha [1,2]. Several factors are listed as impairing maize production. As examples, there is the low use of fertilizers (4-5%), poor post-harvesting procedures, limited use of animal traction (11.3%), low use of improved seeds (only 10% in case of maize OPV's; less than 5% for overall hybrid varieties), fake seeds, limited production area (generally less than three hectares), biotic stresses such as pests and diseases, and abiotic constraints such as drought [5-8].

Since most of the farmers lack financial support for better farming systems such as the application of mineral fertilizer, one of the strategies implemented for circumventing low fertility and reduce the risk of crop failure is the use of intercropping maize/grain legumes [9]. Intercropping is a farming practice involving two or more crop species, or genotypes, growing together and coexisting for a time in the same piece of land [10,11]. Legume–cereal intercropping is common among smallholder farmers in East and Southern Africa, and is used to increase crop production and to maximize land-use, the utilization of labor, and as a strategy to reduce crop risk. It also contributes to increase crop yield stability and diversification of diets [9,12-14]. When legumes and cereals are complementary in terms of growth

* Corresponding author:
abreu@itqb.unl.pt (Abreu I.)
Received: Jun. 8, 2020; Accepted: Aug. 27, 2020; Published: Sep. 26, 2020
Published online at http://journal.sapub.org/ijaf

pattern, aboveground canopy, rooting system, water, and nutrient demand, intercropping can allow a more efficient use of the available resources such as sunlight, water, and soil nutrients), and can lead to a relatively higher yields than crops growing separately. Other benefits of intercropping are related to the better soil cover, which is important for weed control and leads to reduced erosion and nutrient wash. The advantage of using a legume-crop in intercropping relies on the atmospheric nitrogen fixation and, thus, are less likely to compete for nitrogen with the cereal. Also, the use of soil mineral nitrogen by the cereal, may even stimulate legumes to fix more nitrogen [12]. Through rhizosphere acidification and increased release of extracellular phosphatases by the legumes, intercropping also promotes phosphorus assimilation in cereal roots [10,11,15]. This feature of legumes - promoting the assimilation of specific macronutrients is critical because nitrogen is the most important nutrient for maize development [16,17], and phosphorus is probably the most limiting mineral nutrient for plant growth [9,10].

The importance of maize production to meet the populations' demand in Mozambique highlights the need for a continuous process for optimizing the different cropping systems that exist locally, either traditional or modern ones. It also challenges the local farmers to find cheaper and environmentally-friendly alternatives to increase grain yield. Therefore, this study aimed at evaluating different cropping systems through testing the agronomic performance of three maize varieties in rainfed conditions. The knowledge generated would be delivered to improve the local farming practices and contribute to more sustainable maize production. In this work, we tested monocropping and intercropping as traditional practices, and in a later experiment, fertilizer was applied and considered as a modern one. We concluded that maize-cowpea intercropping is more productive than maize production as a monoculture, as well as mineral fertilizer over the non-fertilized fields.

2. Materials and Methods

2.1. Study Areas and Study Design

In the present study, field experiments were conducted consecutively in 2017/2018 and 2018/2019 (from November to March) in two sites of Sussundenga district in Manica province, namely, the Agronomic Stations of Sussundenga (19° 19'02.00" S, 33° 14'25.24" E, 620m above sea level) and Rotanda (19.50000 Latitude 32.91667 longitude, 966m above sea level), with the collaboration of the Agricultural Research Institute of Mozambique (IIAM). Both stations are located about 40km apart. The climate of Sussundenga district is predominantly Tropical Wet Savanna – AW (Köppen Climate Classification) with two distinct seasons, wet and dry. The annual average precipitation is about 1.171 mm. The rain season ranges from November to March, varying significantly in quantity and distribution. The maximum and minimum annual averages temperatures are 29.5 and 17.6℃. The district is also composed of different groups of soils, such as red clayey, red sandy, and medium texture reds, and lytic rocks [28]. The maize varieties used in the experiments, Matuba, ZM309, and ZM523, are improved open-pollinated seeds and well known by the local farmers. They have grain yield potential that ranges from 5000 to 6000 kg/ha [1,6,8,18,19].

The first field experiments were conducted between November 2017 and March 2018. A completely randomized blocks design with three replicates was prepared because experimental the units were considered as essentially homogeneous [20]. Two cropping systems, monoculture (M) and intercropping (I) maize with cowpea *Vigna unguiculata* (L.) Walp., variety IT17 (IIAM) were analyzed. In both sites of experiments, three blocks (each with an area of 20x6m) and a total of nine plots (each with an area of 6x6m) were applied for each cropping system. The experimental units (plots) were composed of eight maize rows and were surrounded by a 1m border of bare ground. Rows at the edge of the plots were considered border rows and were not included in the data collection. Twenty-four maize seeds were sown in each row, with 80 cm spacing between the planting rows and 25 cm within the rows, corresponding to 192 plants per plot (equivalent to 53,333.333 plants/ha). In the intercropped plots, cowpea was planted between the maize rows, totalizing seven rows in each plot spaced 80 cm and 30 cm within the rows, and a total of 20 plants in each cowpea row. The plants were thinned three weeks later, leaving one plant per hole. Maize and cowpea were sown simultaneously, 5-12 cm deep, and always after the beginning of rainfall to ensure proper germination and plant establishment. Fields were prepared by tractors (tillage), hand sowing was carried out, and hand/hoe weeding was performed when needed. Since we intended to perform the experiments as much similar as the most low-income small-scale farmers do, no fertilizer was added at this time. In summary, the treatments were: monocropping (M); strip intercropping (I) maize with cowpea (*Vigna unguiculata* L. (Walp). Soil acidity correction, which is usually done by liming or adding calcium amendments to the soil [21], was not performed in our experiments.

The second field experiments (2018/2019) were conducted similarly to the previous one, but additional plots with mineral fertilizer was included (NPK, 14.76-28.76-14.76) and different sowing times between the two species (also called relay intercropping). The inclusion of fertilizer at this season was to accompany the increasing effort of the local authorities to improve yield through incentives in fertilizer acquisition by the low-income farmers. For the fertilized plots, including in intercropping, a basal application method to apply an equivalent of 178kg of NPK fertilizer per hectare was recommended by the local IIAM Agronomist and used accordingly. The main objective of the fertilizer application was to distribute it uniformly over the fields and to mix it with soil at sowing time. In the second phase, after 30 days of sowing, a top-dressing method to apply an equivalent of 89kg of urea per hectare was implemented. The main purpose was to supply the growing plants with a readily available form of nitrogen for the following plant developmental stages [16]. In summary, the treatments were: monocropping (M); intercropping (I) with cowpea (*Vigna unguiculata* L. (Walp)) without fertilizer use; monocropping with fertilizer application (MF), and intercropping with fertilizer addition (IF). In 2018/2019 experiments, cowpea was sown six weeks after maize sowing to minimize competition between the two species [9,22].

2.2. Soil Sampling and Analysis

In the 2017/2018 season, the soil was sampled and analyzed twice, at sowing and at harvesting times, respectively, in both cropping sites. Three soil depths were considered, 0 to 15 cm, 15 to 30 cm, and 30 to 45 cm, respectively. The samples were analyzed in the Regional Laboratory of Soil and Plant Analysis in Nampula province using the Mehlich-1 method, which is implemented to evaluate soil extractable P. The labile P is extracted by acid dissolution, which preferentially attacks P pools associated with calcium compounds and, to a less extent with aluminum and iron compounds [23]. Data on soil analysis are presented in supplemental Table S1 and S2. Soil analysis was not performed in the second cropping season since no significant differences were expected to occur.

2.3. Statistical Analysis

Data of maize grain yield and plant biomass were analyzed with one-way ANOVA and Tukey test to compare means between varieties within cropping sites. Since relay intercropping and fertilizer were added in the 2018/2019 season, comparisons within cropping seasons were analyzed independently.

Differences were considered significant at $p<0.05$. The statistical analysis was performed using SigmaPlot 11.0 software package (Systat Software Inc., Chicago, IL, USA).

3. Results

3.1. Soil Analysis Data and Weather Conditions in Both Cropping Seasons

Regarding soil properties, the acidity was, in general, slightly higher in Sussundenga. The values of coarse sand were also higher in Sussundenga. However, values of silt, clay, humidity, Ca, Mg, organic matter, sum of exchangeable cations of negligible acidity, capacity of cation exchange, and rate saturation were slightly higher in Rotanda. The values of fine sand, extractable phosphorus, and soil density were fluctuant in both locations (see supplemental Tables S1 and S2 for more details). The rainfall abundance and distribution varied between the cropping seasons. In the 2017/2018 season, the maximum mean air temperature in Sussundenga Station over the cropping season was ~28.0℃ and the total precipitation was 2135.5 mm. Rotanda recorded ~28.0℃ of maximum temperature and 1056 mm of total precipitation. In the 2018/2019 season, Sussundenga recorded maximum temperatures rounding ~29.0℃, and 1654 mm of precipitation, while in Rotanda 700 mm and ~29.0℃ was recorded for precipitation and maximum temperature, respectively (Supplemental Figures S1 and S2). In summary, Sussundenga recorded the highest rainfall abundance in both seasons.

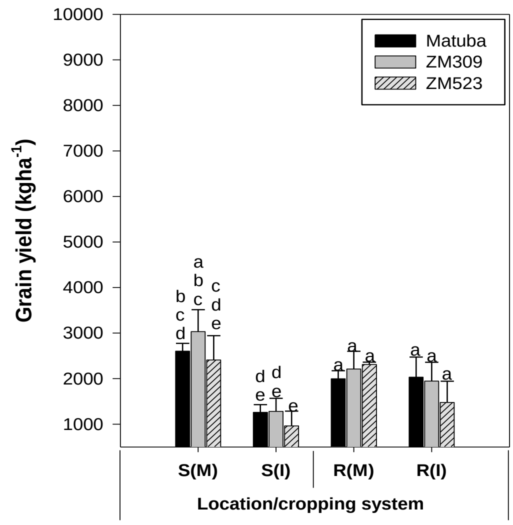

Figure 1. Grain yield in 2017/2018 season. S (Sussundenga); R (Rotanda); M (monocropping); I (intercropping maize/cowpea). Bars are an average of three plots±SE. Different letters indicate statistical significance of the differences among varieties within locations (one-way ANOVA, Tukey test, *p<0.05*)

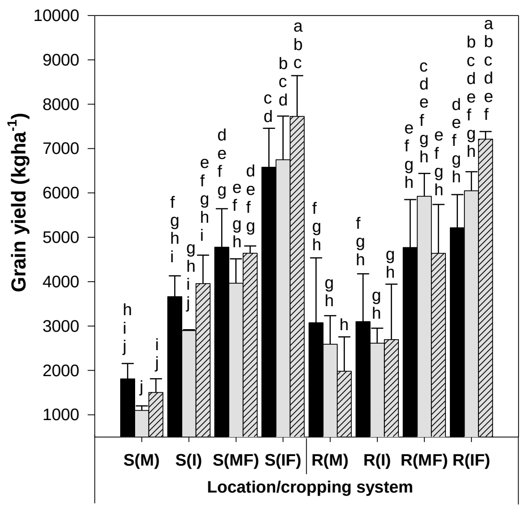

Figure 2. Grain yield in 2018/2019 in season. S (Sussundenga); R (Rotanda); M (monocropping); I (intercropping maize/cowpea); F (mineral fertilizer use). Bars are an average of three plots±SE. Since relay intercropping and fertilizer were added as new factors in the second season, the 2017/2018 and 2017/2018 statistical analyses were made independently. Different letters indicate statistical significance of the differences among varieties within locations (one-way ANOVA, Tukey test, *p<0.05*)

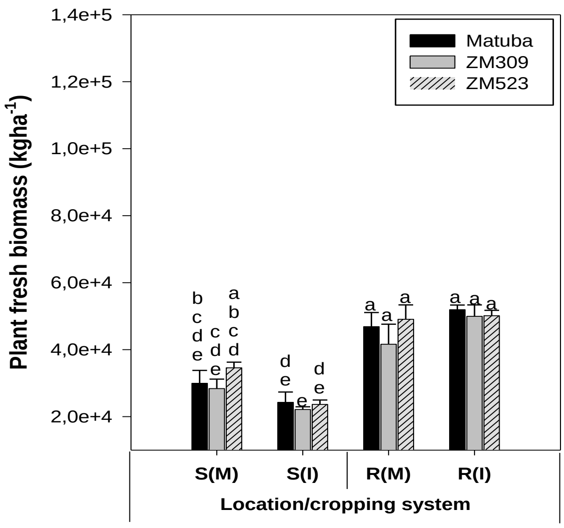

Figure 3. Plant fresh biomass in 2017/2018 season. S (Sussundenga); R (Rotanda); M (monocropping); I (intercropping maize/cowpea). Different letters indicate statistical significance of the differences among varieties within locations (one-way ANOVA, Tukey test, $p<0.05$)

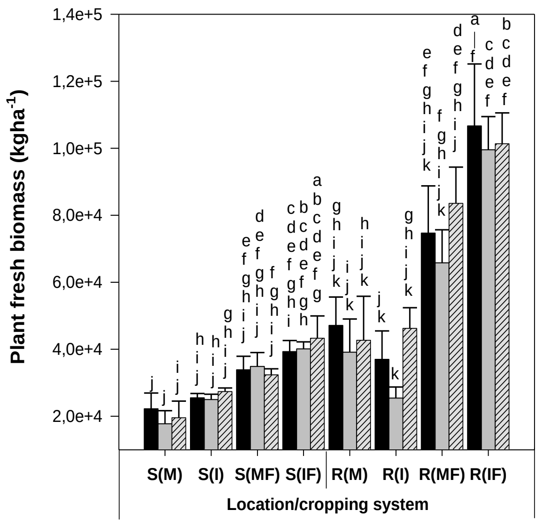

Figure 4. Plant fresh biomass in 2018/2019 season. S (Sussundenga); R (Rotanda); M (monocropping); I (intercropping maize/cowpea); F (mineral fertilizer use). Bars are an average of three plots±SE. Since relay intercropping and fertilizer were added as new factors in the second season, the 2017/2018 and 2017/2018 statistical analyses were made independently. Different letters indicate statistical significance of the differences among varieties within locations (one-way ANOVA, Tukey test, $p<0.05$)

3.2. Grain Yield and Plant Biomass Assessment in the 2017/2018 Cropping Season

In the first season, we obtained maize grain yields ranging from 2410.4 to 3033.5 kg/ha in monocropping in Sussundenga, and 961.9 to 1282.9 kg/ha in intercropping. In Rotanda, maize grain yields ranged from 1996.2 to 2310.7 kg/ha in monocropping and 1478 to 2034kg/ha in intercropping (Figure 1). All these values were above the local estimated yield of 300 - 900 kg/ha [1,2]. Although not applying mineral fertilizer at this time, the use of improved seeds, the disease control, and the application of the correct plant spacing, might have contributed to the improved yield over the local average, where the majority of small local farmers do not use improved seeds, mineral fertilizer or disease control through chemicals.

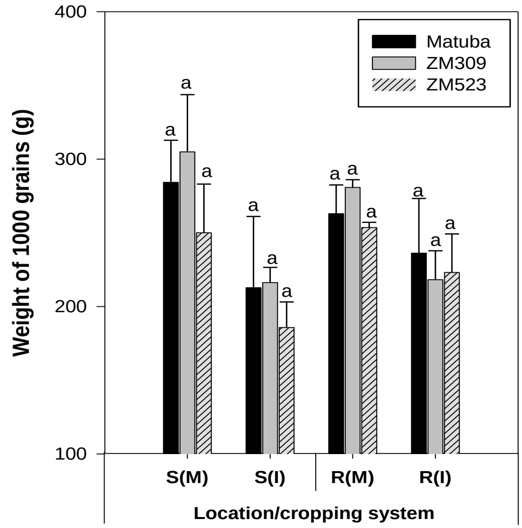

Figure 5. The weight of 1000 grains in 2017/2018 season. S (Sussundenga); R (Rotanda); M (monocropping); I (intercropping maize/cowpea); F (mineral fertilizer use). Bars are an average of three plots±SE. Different letters indicate statistical significance of the differences among varieties within locations (one-way ANOVA, Tukey test, $p<0.05$)

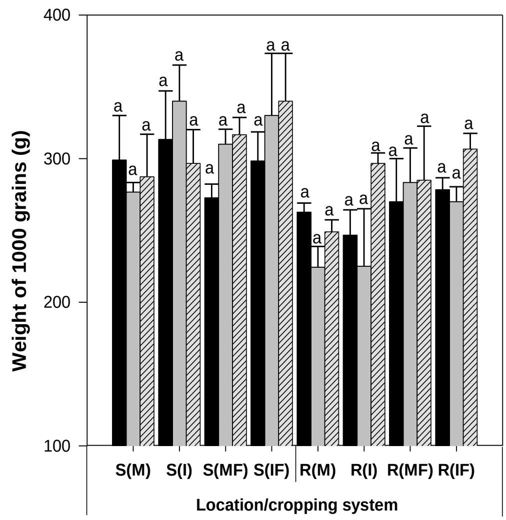

Figure 6. The weight of 1000 grains in 2018/2019 season. S (Sussundenga); R (Rotanda); M (monocropping); I (intercropping maize/cowpea); F (mineral fertilizer use). Bars are an average of three plots±SE. Different letters indicate statistical significance of the differences among varieties within locations (one-way ANOVA, Tukey test, $p<0.05$)

Although not always finding statistical differences, the tendency of grain yield, plant biomass, and weight of 1000 grains in Sussundenga was lower in intercropping when compared to monocropping (Figures 1, 3, and 5). For example, we recorded a 50% to 60% reduction in grain yield, and a 19% to 32% in plant biomass. These reductions can be an indication that intercropping did not improve yield over monocropping in Sussundenga. The tendency for lower grain yield in intercropping was also observed in Rotanda but was much less prominent than in Sussundenga, indicating that competition affected both sites but in different manner (Figure 1). Therefore, the yield in Rotanda was more comparable between cropping systems. Additionally, plant biomass was higher in Rotanda (Figure 3). We observed an average of 48% increase in monocropping and a 117% increase in intercropping when compared to Sussundenga. However, the above tendency was not general, since grain yield and weight of 1000 grains were slightly lower in monocropping if compared to the same treatment in Sussundenga (Figures 1 and 3). The tendency for higher biomass in Rotanda was also observed in the second cropping season, including in fertilizer treatments, as well as for the lower weight of 1000 grains (Figures 4 and 6).

3.3. Grain Yield and Plant Biomass Assessment in the 2018/2019 Season

Based on the possibility that the competition for soil nutrients would be contributing to the adverse effects in intercropping in Sussundenga in 2017/2018, we decided to desynchronize the sowing times of the two species in the next season - relay intercropping. Although the majority of the small-scale farmers do not use fertilizers because of the high cost, we introduced plots with mineral fertilizer to assess its effects in maize yield and plant biomass. Studying the influence of fertilizer was important because although the percentage of fertilizer adoption in Mozambique is low, there is an increasing effort from the local government on incrementing the use of inorganic fertilizer among small-scale farmers through direct financing. We obtained grain yields ranging from 1100 to 1809.3 kg/ha and 2897.7 to 3958.4 Kg/ha in monocropping and intercropping, respectively, in Sussundenga without fertilizer. The monocropping maize plots with fertilizer yielded 3966.3 to 4777kg/ha, and for the intercropped plots, we recorded 6580 to 7726.1 kg/ha. Without the use of fertilizer, we recorded grain yields ranging from 1980.1 to 3077kg/ha and 2613.8 to 3100kg/ha, in monocropping and intercropping, respectively, in Rotanda. The monocropping maize plots with fertilizer yielded from 4639.7 to 5925kg/ha, while the intercropping, from 5214.3 to 7213.5 kg/ha (Figure 2).

On the 2018/1019 season, intercropping (with staggered sowing times) in Sussundenga recorded at least a two-fold increase in grain yield in all varieties compared to monocropping. Also, the combination of relay intercropping and mineral fertilizer increased maize yield and plant biomass than any other treatments (Figures 2 and 4). In Rotanda, mineral fertilizer in monocropping contributed with a 56% to 135% increase in grain yield when compared to the non-fertilized monocropping. Also, 68% to 167% increase was observed in the combination of intercropping and mineral fertilizer over intercropping alone. The plant fresh biomass was the parameter that recorded the highest increase in fertilized treatments, being almost two-fold or higher than the non-fertilized ones (Figure 2).

4. Discussion

As described above, the data collected in the first season showed visible reductions in grain yield and biomass production in intercropping in Sussundenga. At the same time, for Rotanda, this tendency was less notable. Additionally, yield in Rotanda was more stable and balanced across seasons. Regarding this tendency for reductions in the first season in Sussundenga, several hypotheses were considered. Higher competition between the two species for soil resources (interspecific competition), with cowpea possible dominating over the maize, was one of them. Additionally, the sandy soil in Sussundenga that is much susceptible to soil surface runoff could contribute to the loss of nutrients, to increase competition, and consequently to the low productivity of maize (Supplemental Tables S1 and S2).

The above possibility to explain the tendency in Sussundenga is also supported by the fact that not all intercropping systems provide benefits in terms of grain yield. The asymmetric distribution of capture organs can lead to the dominance relationships between crops, which can affect their performance. Thus, the benefits of intercropping will depend on the availability of resources such as solar radiation, water, soil nutrients, and every condition influencing the phenology and growth of each species [11].

Another possibility is that, at the grain filling stage, nodule senescence had already occurred, impairing the beneficial effects of intercropping at a very critical developmental stage for productivity [16]. In this sense, nitrogen would have been mainly used during vegetative stage rather than at the reproductive stage. If this was the case, relay intercropping, implemented in the second season, could possibly minimize this effect. In relay intercropping, nitrogen-fixing legumes are introduced between silking and physiological maturity of maize [25,26]. The legumes continue to grow after the cereal harvest throughout the off-season. As farmers prepare the land for the next season, they can clear-cut the legume and incorporate the remaining biomass into the soil [26]. This staggering of the planting dates in the intercropped system can reduce competition between intercropped plants. Staggered planting is also used for reducing the risk of total crop failure when expected rainfall is uncertain [9]. Additionally, relay intercropping can be important to compensate nitrogen demand in the later stage of growth in maize and considered as a sustainable and efficient system of nitrogen-use under reduced fertilizer application [27]. Therefore, the data obtained in the second season with relay intercropping improving maize yield and biomass in Sussundenga, support the beneficial effects described above.

The reported smaller effect of intercropping on maize yield in Rotanda in both cropping seasons can probably be explained by the specific soil properties in that location. For instance, values of clay, the sum of exchangeable cations, the capacity of cation exchange, the rate of base saturation, the levels of Mg, K, and Ca were higher in Rotanda than in Sussundenga. Also, the pH levels in Sussundenga was in general lower compared to those recorded in Rotanda (supplemental Tables S1 and S2.). These features corroborate the observation made in previous soil characterization performed by [28], which reported sandy soils of Sussundenga Station as acidic soils with dominant features such as the presence of exchangeable aluminum and low amount of exchangeable hydrogen and low cation exchange capacity. Soil acidity can cause serious soil fertility problems, affecting nutrients bioavailability, and indirectly plant growth [29]. For example, calcium and magnesium uptaken by plants are replaced by aluminum, resulting in nutrient deficiencies and reduced yields [28]. Therefore, we suggest that under the presented soil properties, maize was not capable of capturing enough nutrients under interspecific competition in Sussundenga, in opposition to Rotanda.

The use of mineral fertilizer in maize alone in the second season contributed to increasing grain yield which was aligned with previous reports [9,17,30], highlighting how much nutrient-availability is limiting the production in this region. The increased grain yields highlighted the positive impact of proper fertilization and the need to monitor soil quality continuously. Fertilization should be applied in Mozambique to improve soil quality and achieve increased grain production and quality. However, fertilizer application should be made within a correct and environmentally-friendly soil management plan in order to prevent putative environmental damages.

The combination of intercropping and mineral fertilizer in the second season also contributed to increasing maize yield and plant biomass, when compared to the other treatments. In this case, the fertilizer could contribute to improving nitrogen fixation. For example, in work developed by [26], they analyzed the effects of phosphorus application on the biological nitrogen fixation of herbaceous legumes. They observed a higher number of nodules and total dry weight matter in phosphorus treatment when compared to the control, which confirmed its positive effect on the formation and activity of nodules in fixing N_2 [15]. Also, significant advantages on carbon and nitrogen accumulation in plant tissues were found in intercropping with mineral fertilization [31], as well as an improvement in cereal yields by 71-282% and reductions in its variability by 40-56% [14].

Another notable aspect found in our study was the tendency for higher plant biomass in Rotanda in both seasons. To explain this, we hypothesized that nitrogen recovery efficiency (NRE) should be higher in Rotanda - but not necessarily the Nitrogen Internal Efficiency (NIE). The NRE reflects the ability of aboveground plant parts to recover N from the soil, while NIE reflects the capability of the plants to transform N took up by the crop into the grain [10,32]. Thus, probably specific environmental factors in Rotanda during the grain filling period may have affected the translocation efficiency of nitrogen and sugars that accumulated during the pre-anthesis stage [33,34].

Although based on the limited number of experiments, our data show a tendency for less variability across seasons in Rotanda as well as for a more comparable yield between monocropping and intercropping. Thus, we recommend Rotanda as probably a better place for intercropping use as compared to Sussundenga.

The advantages of fertilizer use can unfortunately be affected by its high cost. For example, in 2012, the cost per 50 kg bag of NPK 12:24:12 and urea in Mozambique was estimated at US $ 41.35 and US $ 37.59, respectively, in the main agricultural areas of Manica and Sofala provinces [35]. However, currently, the minimum national salary in the agrarian sector rounds only 4,390 meticais (US $ 62), which lowers the capacity of the population to acquiring agricultural inputs.

On the other hand, at the beginning of 2020, the cost of kg of maize grain was estimated at 25 meticais (US $ 0.35) in Maputo city, the capital of Mozambique (source: Ministry of Industry and Trade, www.mic.gov.mz). Thus, the highest yield of 7726.1 kg/ha reported in the present study could yield 193,152.5 meticais (US $ 2,720), and compensate for the cost of the seeds (about US $ 1.4 per kg), fertilizer, and chemicals use. Thus, the government incentives to increase the use of fertilizer should be maintained.

5. Conclusions

Our data suggest that intercropping can be considered as a good practice to increase grain yield particularly if proper optimization of the practice, such as the planting time, is performed. Additionally, fertilizer-application was considered crucial for enhancing the performance of monocropping and intercropping. Intercropping should be seen as a sustainable strategy to circumvent low soil fertility and compensate for the shortage of financial resources to buy fertilizers among local farmers.

ACKNOWLEDGEMENTS

The authors wish to thank the Agricultural Productivity Program for Southern Africa (APPSA) and the Agricultural Research Institute of Mozambique (IIAM) for providing the means for the success of the experiments, and the University Púnguè for the conditions provided to DM that allowed to develop his Ph.D. work. This work was supported by Fundação para a Ciência e a Tecnologia through the R&D Unit GREEN-IT-Bioresources for Sustainability (UID/Multi/04551/2013, UID/Multi/04551/2018 and UIDB/04551/2020). Dizimalta Miquitaio's Ph.D. training was funded by the FCT (Foundation for Science and

Technology of Portugal) through the fellowship PD/BD/128391/2017 within the scope of the Graduate Program for Science and Development Ph.D. Program (PGCD). Isabel Abreu was supported by the FCT Investigator IF/00764/2014 (POPH-QREN). The funding sources had no involvement in study design, analyses, and interpretation of data, writing, or in the submission decision.

REFERENCES

[1] Tomo, A. and Alberto, M. 2016. Mozambique early generation seed study.

[2] Stevens, R. and Winter-Nelson, A. 2008. Consumer acceptance of provitamin A-biofortified maize in Maputo, Mozambique. Food Policy, 33, 341–351.

[3] Dias, P. 2013. Analysis of incentives and disincentives for maize in Mozambique.

[4] Silici, L., Bias, C., Cavane, E. 2015. Sustainable agriculture for small-scale farmers in Mozambique, a scoping report.

[5] PEDSA 2011. Plano Estratégico Para o Desenvolvimento do Sector Agrário 2011-2020 (Strategic Plan for the Development of the Agrarian Sector of Mozambique).

[6] Come, F., Neto, F. 2017. Adoção da variedade de milho Matuba pelos pequenos produtores do distrito de Sussundenga, Moçambique (Adoption of the matuba maize variety by small farmers in the district of Sussundenga, Mozambique). Rev. em Agronegócio e Meio Ambient., 10, 977–994.

[7] FAO 2015. Programa da FAO em Moçambique (2012-2015).

[8] Mabaya, E. 2017. Mozambique Brief 2017 - The African Seed Access Index.

[9] Rusinamhodzi, L., Corbeels, M., Nyamangara, J., Giller, K. E. 2012. Maize – grain legume intercropping is an attractive option for ecological intensification that reduces climatic risk for smallholder farmers in central Mozambique. F. Crop. Res., 136, 12–22.

[10] Yan, S., Du, X., Wu, F., Li, L., Li, C., Meng, Z. 2014. Proteomics insights into the basis of interspecific facilitation for maize (*Zea mays*) in faba bean (*Vicia faba*)/maize intercropping. J. Proteomics, 109, 111–124.

[11] Brooker, R.W., Bennett, A. E., Cong, W.F., Daniell, T.J., George, T.S., Hallett, P.D., Hawes, C., Lannetta, P.P.M., Jones, H.G., Karley, A.J., Li, L., McKenzie, B.M., Pakeman, R.J., Schöb, C., Shen, J., Squire, G., Watson, C.A., Zhang, C., Zhang, F., Zhang, J., White, P.J. 2015. Improving intercropping: a synthesis of research in agronomy, plant physiology and ecology. New Phytol., 206, 107–117.

[12] Mucheru-Muna, M., Pypers, P., Mugendi, D., Kun'g, J., Mugwe, J., Merckx, R.., Vanlauwe, B. A. 2010. Staggered maize – legume intercrop arrangement robustly increases crop yields and economic returns in the highlands of Central Kenya. F. Crop. Res., 115, 132–139.

[13] Bybee-Finley, K. A., Ryan, M. R. 2018. Advancing intercropping research and practices in industrialized agricultural landscapes. Agriculture, 80, 1–24.

[14] Kiwia, A., Kimani, D., Harawa, R., Jama, B., Sileshi, G. W. 2019. Sustainable Intensification with cereal-legume intercropping in Eastern and Southern Africa. Sustainability, 11, 1–18.

[15] Franke, A. C., Van Den Brand, G. J., Vanlauwe, B., Giller, K. E. 2018. Sustainable intensification through rotations with grain legumes in Sub-Saharan Africa: A review. Agric. Ecosyst. Environ., 261, 172–185.

[16] Abebe, Z. and Feyisa, H. 2017. Effects of nitrogen rates and time of application on yield of maize: rainfall variability influenced time of N application. Int. J. Agron., 2017, 1–10.

[17] Jiang, C., Lu, D., Zu, C., Zhou, J., Wang, H. 2018. Root-zone fertilization improves crop yields and minimizes nitrogen loss in summer maize in China. Sci. Rep., 8, 1–9.

[18] Aslam, M., Maqbool, M. A., Cengiz, R. 2015. Drought stress in maize (*Zea mays* L.) effects, resistance mechanisms. Global Achievements and Biological Strategies for Improvement. Springer Pakistan, 1-74.https://www.springer.com/gp/book/9783319254401.

[19] Setimela P. and Thierfelder, C. Variedades de Milho de Polinização Aberta (OPVs) (Open-pollinated maize varieties). Instituto de Investigação Agrária de Moçambique.

[20] Davis, R., Harris, G., Roberts, P., Macdonald, G. 2017. Designing research and demonstration tests for farmers' fields. UGA Extension, 8p.

[21] Carter, M. R.; Gregorich, E. G. 2006. Soil Sampling and Methods of Analysis. Taylor & Francis Group, New York, 1-198.

[22] Kimaro, A. A., Timmer, V. R., Chamshama, S.A.O., Ngaga, Y.N., Kimaro, D.A. 2009. Competition between maize and pigeonpea in semi-arid Tanzania: effect on yields and nutrition of crops. Agric., Ecosyst. Environ., 134, 115–125.

[23] Gatiboni, L. C., Menotti, C., Oliveira, B. D., Roberto, P., Jaime, E.A. 2010. Soil available phosphorus by Mehlich-1, Mehlich-3 and anion exchange resin and its sensitivity to soil clay content. 19th World Congress of Soil Science, Soil Solutions for a Changing World, Brisbane, Australia, 139–142.

[24] USAID 2016. Mozambique early generation seed study. https://www.agrilinks.org/sites/default/files/resource/files/mozambique_early_generation_seed_report.pdf.

[25] Niringiye, C., Ssekabembe, C., Kyamanywa, S. 2005. Effect of plant population on yield of maize and climbing beans grown in intercropping system. African Crop Sci. Soc., 13, 83–93.

[26] Velasco, V.V., Salgado, S., Cardenas, R. 2008. Influence of P fertilization on biological nitrogen fixation in herbaceous legumes grown in acid savannah soils from the Tabasco State, Mexico. J. Sustain. Agric., 0046, 25–42.

[27] Du, Q., Zhou, L., Chen, P., Liu, X., Song, C., Yang, F. 2019. Relay-intercropping soybean with maize maintains soil fertility and increases nitrogen recovery efficiency by reducing nitrogen input. The Crop J., 8, 140-152.

[28] Wijnhoud, J. D. 1997. Solos e outros recursos naturais da

Estação Agrária de Sussundenga (Soils and other natural resources from the Sussundenga Agrarian Station). Série Terra e Á gua: Maputo, 41p.

[29] Goulding, K. W. 2016. Soil acidification and the importance of liming agricultural soils with particular reference to the United Kingdom. Soil Use Manag., 32, 390–399.

[30] Akongwubel, A. O., Ewa, U.B., Prince, A., Jude, O., Martins, A., Simon, O., Nicholas, O. 2012. Evaluation of agronomic performance of maize (*Zea mays* L.) under different rates of poultry manure application in an Ultisol of Obubra, Cross River State, Nigeria. Int. J. Agric. For., 2, 138–144.

[31] Zhao, Y., Fan, Z., Hu, F., Yin, W., Zhao, C., Yu, A. 2019. Source-to-Sink translocation of carbon and nitrogen is regulated by fertilization and plant population in maize-pea intercropping. Front. Plant Sci., 10, 1–15.

[32] Wang, Z.; Ma, BL.; Yu, X.; Gao, J.; Sun, J.; Su, Z.; Yu, S. 2019. Physiological basis of heterosis for nitrogen use efficiency of maize. Sci. Rep., 9, 1–11.

[33] Barbottin, A., Lecomte, C., Jeuffroy, M. 2005. Nitrogen remobilization during grain filling in wheat. Crop Sci., 45, 1141–1150.

[34] Zhou, B.; Serret, M. D.; Pie, J. B.; Shah, S. S. 2018. Relative Contribution of nitrogen absorption, remobilization, and partitioning to the ear during grain filling in Chinese winter wheat. F. Crop. Res., 9, 1–11.

[35] IFDC, 2012. Mozambique Fertlizer Assessment. Alabama, U.S.A.