Article

Pigeonpea Yield and Water Use Efficiency: A Savior under Climate Change-Induced Water Stress

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Abstract: Frequent droughts have threatened the crop yields and livelihoods of many smallholder farmers in South Africa. Pigeonpea can be grown by farmers to mitigate the impacts of droughts caused by climate change. An experiment was conducted at Fountainhill Farm from January 2016 to December 2017. The trial examined grain yield in addition to water use efficiency (WUE) of pigeonpea intercropped with maize versus sole pigeonpea and maize. A randomized complete block design, replicated three times, was used. Soil water tension was measured at 20, 50, and 120 cm within plots. The highest and lowest soil water tension was recorded at 20 m and 120 m respectively. Combined biomass and grain yield were significantly different: pigeonpea + maize (5513 kg ha⁻¹) > pigeonpea (3368 kg ha⁻¹) > maize (2425 kg ha⁻¹). A similar trend was observed for WUE and land equivalent ratio (LER), where pigeonpea + maize outperformed all sole cropping systems. The inclusion of pigeonpea in a traditional mono-cropping system is recommended for smallholder farmers due to greater WUE, LER and other associated benefits such as food, feed and soil fertility amelioration, and it can reduce the effects of droughts induced by climate change.

Keywords: drought; food security; intercropping; smallholder farmers

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1. Introduction

Climate change and variability have threatened crop production, which has left many smallholder farmers facing food insecurity, as well as having a devastating effect on people's livelihood [1,2]. Agriculture in South Africa (RSA) is facing diverse risks interconnected to climate change, which encompasses shifts in rainfall patterns, increased evaporation rates, higher temperatures, and reduction in crop yields [3]. Most smallholder farmers in RSA till on marginal areas distinguished by low and unpredictable rainfall, and sandy soils with little organic matter, in addition to low nutrient content [4]. Farming practices in such environments are risky and unreliable, which leads to low income and poverty in the rural households relying on agriculture for their livelihood. The emergence of such risks calls for critical, formidable action to ensure the resilience of the RSA sector via adoption of drought tolerant or resilient crops such as pigeonpea [5]. Pigeonpea (*Caenjanus cajan* (L.) Millsp) is an important drought tolerant legume crop that can be adopted by smallholder farmers in the advent of climate change and variability [5]. According to the International Maize and Wheat Improvement Center [6], pigeonpea is a main contributor to food security in regions experiencing the early impacts of global climate change. Legume-cereal mixed farming provides subsistence food production in low-income nations, mostly in circumstances of drought [7]. In RSA, pigeonpea is among the most underutilized pulse legume crop and it is not grown on fields [8,9]; usually, the crop is grown as a live fence in home gardens in Mpumalanga, Limpopo and KwaZulu-Natal provinces [8]. Despite a huge potential market for this crop among the Asian community in the country, this opportunity has not been fully exploited. Approximately 120–150 tonnes are imported from Malawi every month to meet the ever-growing demand for the Indian cuisine known as

dhal [10]. The crop can be used as a legume option to serve the increasing demand for nutritional foods, as it is high in protein, vitamins, and essential minerals [9,11]. In a review by Odeny [5], pigeonpea planted as a sole crop may fix up to 235 kg N ha⁻¹ via biological nitrogen fixation (BNF) and it has the ability to release more nitrogen from plant biomass under certain conditions as compared to other legumes. In addition to this, the roots of pigeonpea can grow quite deep, which makes it better in terms of anchoring the soil, thereby withstanding severe drought as compared to shallow-rooted legumes such as cowpea, groundnut, and soybean.

Furthermore, when integrated into cropping system as a simultaneous or sequential agroforestry system, pigeonpea may enhance soil structure, thereby increasing the water-holding capacity and allowing moisture retention for a longer duration following a rainfall episode. However, some research has shown that a substantial quantity of the water received may be lost through evaporation or by deep percolation [12–14]. Water abstraction by a rooting system of a crop is governed by accessibility, spatial distribution and the biomass of the roots, besides other activities in the rhizosphere. When computing the water balance, some constituents (drainage, run-off, and soil evaporation) does not aid crop productivity. Despite the fact that pigeonpea intercropped with maize can increase overall productivity and water use efficiency (WUE) by diminishing these unproductive constituents [15], intercropping pigeonpea with maize also has the ability to enhance land productivity as determined by the land equivalent ratio (LER) [10]. Meng and Zhang [16], recorded a LER of 1.19 in a pear agroforestry system and Zhang et al. [17] also found a LER of 1.24–1.45 in a jujube agroforestry system and Zhang et al. [18] observed LER of 1.28–1.39 on cotton intercropped with wheat. According to Smith et al. [19], LERs on agroforestry systems may even reach up to 2.0. An increase in land productivity under agroforestry or intercropping systems [20–23] can be attributed to numerous factors, such as increased radiation capture [24], higher radiation use efficiency [25], reduction in soil evaporation [26], enhanced soil fertility [27], and improved soil properties [28]. However, much of the cereal–pigeonpea intercropping research in Africa has focused on comparing yields in intercrops with sole maize [29–31]. WUE may be higher under intercropping systems as compared to mono-cropping systems [32]. Ghanbari et al. [33] also recorded higher WUE in maize intercropped with cowpea. There is a paucity of scientific data on whether pigeonpea intercropped with maize in RSA has higher productivity and WUE than mono-cropping systems of sole pigeonpea or maize without fertilizers [29,34–36].

Maize (*Zea mays* L.) is a mainstay crop which can be utilized for both human and livestock feed in RSA [37–39]. However, water scarcity because of erratic rainfall, which can be caused by climate change and variability, has led to low crop yields, or in some instances, total maize crop failure [2–4]. Currently, quantification of pigeonpea yield and WUE on pigeonpea intercropped with maize has not been studied in RSA. Smallholder farming practices depend on rainfall; however, recurrent incidences of dry spells throughout the growing season have become the norm because of climate change. In reality, soil water status is of great significance for smallholder farmers who do not have the capacity to supplement with irrigation when dry spells occur. Nevertheless, it is important to generate scientific data on pigeonpea yield and WUE specifically for RSA, because many promising results have been found in previous studies [40–42] which revealed that pigeonpea intercropped with maize may increase water use efficiency in water limited environments compared to a traditional sole maize cropping system [42]. In addition, pigeonpea is a drought-tolerant crop which can withstand harsher conditions than maize crop. Under such circumstances, farmers ought to be given useful data pertaining to the use of scant or erratic rainfall in order to enhance crop productivity and ensure food security [43]. Hence, the hypothesis of this study was that intercropping pigeonpea with maize will result in higher total land productivity and increased water use efficiency as compared to a mono-cropping system. For this reason, this study examined the yield and WUE of pigeonpea intercropped with maize versus sole cropping systems of both pigeonpea and maize.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted on sandy loam soil categorized as ferralsol by the Food and Agriculture Organization of the United Nations (FAO) classification system [44], from December 2015 to December 2017 at Fountainhill Estate Farm (29°27'2" S: 30°32'42" E) with an altitude of 850 m in Wartburg, which is situated northeast of Pietermaritzburg, South Africa. The annual minimum and maximum temperatures are 3.3 °C and 37.4 °C, respectively, with an annual rainfall that ranges from 700–900 mm. Before trial establishment, soil samples were collected using a 2-cm diameter soil auger from 0–20 cm soil depth in each plot. The soil samples were analyzed for pH, N, P, K, and organic carbon using the methods explained by the International Institute of Tropical Agriculture (IITA) [45]. The soil was acidic with a low organic carbon content and high concentration of calcium and potassium. The results of the initial soil characterization are presented in Tables 1 and 2.

Table 1. Soil chemical properties at Fountainhill Estate Farm, Wartburg, Source: Musokwa et al. [11].

Parameter	Value
Nitrogen (%)	0.06
Phosphorus (mg kg ⁻¹)	20.4
Potassium (mg kg ⁻¹)	114.2
Calcium (mg kg ⁻¹)	488
Magnesium (mg kg ⁻¹)	95.6
Copper (mg kg ⁻¹)	2.98
Total cations (c mol kg ⁻¹)	3.594
Organic carbon (%)	0.65
pH (KCl)	4.37

Table 2. Soil physical characteristics within rooting depth in the study site.

Depth (cm)	Clay %	Silt %	Sand %	Porosity %	Texture
20	14.2	2.4	83	20	Loamy sand
50	24.3	2.6	72.2	25.8	Sandy clay loam
120	28.1	3.0	67.3	37	Sandy clay loam

2.2. Trial Design, Establishment and Management

This study had three treatments in the first season (2016); they were as follows: sole maize, sole pigeonpea and maize intercropped with pigeonpea. In the second season (2017), maize was planted again while the treatments which had pigeonpea continued for two seasons (i.e., sole maize, sole pigeonpea and the pigeonpea which had maize in the previous season (2016)). The treatments were laid out in a randomized complete block design and replicated three times. The gross plots were 6 m × 8 m (the total area of the plots), while the net plots were 7 m × 5 m (the area meant for harvesting). Plants situated on the gross plot are excluded from the sample harvest in order to remove any plot border effects; hence, the net plot provides the harvesting area. Both intercrop and sole crops were sown on the first week of January 2016, at a spacing of 1 m × 1 m, with a population of 10,000 plants ha⁻¹. Pigeonpea (landrace) with a physiological maturity of 285 days was used. Maize (border king variety), which matures in approximately 120 days, was planted at a spacing of 0.80 m × 0.5 m to make a total plant population of 25,000 plants ha⁻¹. The pigeonpea–maize intercrop had 1 m × 0.40 m spacing of maize to maintain the same plant population of sole maize (25,000 plants ha⁻¹), while the pigeonpea maintained the same spacing of 1 m × 1 m and a total population of 10,000 plants ha⁻¹. Two hand weeding operations were executed per season. No fertilizer was applied to the treatments throughout the study period to mimic smallholder practices, where they do not apply chemical fertilizers.

2.3. Determination of Soil Water Content and Water Use (WU)

Soil watermark sensors (Campbell Scientific Africa Pvt Ltd., Cape Town, South Africa) were positioned at depths of 20, 50, and 120 cm on the treatment plots and demarcated by 90 cm from each other to measure the soil water tension in kilopascals (kPa). Once the soil water mark sensors were installed, they measured soil water tension continuously (recording every hour), and there is no soil disturbance [46]. These three soil depths were selected based on the fact that maize roots are most concentrated in 20–50 cm soil profile, and the 120 cm depth was chosen with an assumption that pigeonpea tree roots would capture deep soil water [47–49]. Retention curves developed from uninterrupted soil cores (1.5 cm height and 1.5 cm diameter) were collected using desorption, applying standard techniques [50], and analyzed in terms of the empirical retention model of van Genuchten using the Retention Curve (RETC) computer program (United States Environmental Protection Agency, Washington, DC, USA) [51,52]. Soil water retention curves were used to convert soil water tension (kPa) to volumetric water content ($\text{cm}^3 \text{cm}^{-3}$), which was applied in determining water use.

The amount of water in the soil profile between the surface and depth x was calculated as shown in Equation (1):

$$S(0, x) = \int_0^x \theta \cdot dx, \quad (1)$$

where $S(0, x)$ is the quantity of water available in the soil (mm) to a depth x , θ is the amount of water content ($\text{cm}^3 \text{cm}^{-3}$), and dx is the thickness of the soil (cm).

Runoff and drainage were regarded as unimportant due to the relatively flat field used as the study site, which had a 2% slope. Actual water use was determined using the water balance, as shown in Equation (2) [53]:

$$\text{Water Use} = \text{Rainfall (mm)} + \text{changes in Water Content (mm)}, \quad (2)$$

Total rainfall is for the growing season, while the changes in soil water content are at planting (minus at physiological maturity).

2.4. Aboveground Biomass Matter and Grain Yield Measurements

Both maize and pigeonpea were harvested when they reached physiological maturity, while dry matter sampling was conducted at critical crop development stages. The samples were put in an oven for 30 min at 105 °C. The yield was harvested from the central rows (net plot), measuring 35 m²; they were weighed by a digital scale before shelling. Moisture content was measured using an electronic Agatronix moisture tester MT-16 (Campbell Scientific Africa Pvt Ltd., Cape Town, South Africa), after which the final seed yield was adjusted to 12.5% prior to weighing.

To evaluate land productivity in an intercropping or simultaneous agroforestry system, the land equivalent ratio (LER) was applied. The LER is defined as the relative area of land needed in the sole cropping system to bring about the matching yield obtained in an intercrop or agroforestry system [54]. Sole cropping systems are regarded as having LER values of 1 or <1, while a LER >1 stipulates higher productivity in intercropping or agroforestry systems [55]. The LER of intercropping or agroforestry systems is determined by adding the partial LERs of each individual crop and tree components in an intercropping or agroforestry system [54,55]:

$$\text{LER} = \frac{(\text{crop yield in agroforestry}) + (\text{tree yield in agroforestry})}{(\text{crop yield in monoculture}) + (\text{tree yield in monoculture})} \quad (3)$$

Water use efficiency (WUE) was only calculated on total aboveground biomass matter and grain yield kg ha^{-1} divided by the total evapotranspiration (water used) over the growing period [53], as shown in Equation (4):

$$\text{WUE} = \frac{Y}{\text{WU}} \left(\text{kg mm}^{-1} \right) \quad (4)$$

where Y is the yield (kg ha^{-1}), and WU is the total actual evapotranspiration (water used) by the cropping system during the growing season (computed using the simplified water balance formula in Equation (2) [53]).

WU is not separated into different species in intercropping systems because of overlapping root systems. To characterize the water use efficiency of the whole intercropping system (pigeonpea and maize crop combined), the water equivalent ratio (WER) was used by Mao et al. [56]. This measure is defined by analogy with LER as shown in Equation (5):

$$\text{WER} = \text{WER}_A + \text{WER}_B = \frac{Y_{\text{int}, A} / \text{WU}_{\text{int}} + Y_{\text{int}, B} / \text{WU}_{\text{int}}}{Y_{\text{sole}, A} / \text{WU}_{\text{sole}, A} + Y_{\text{sole}, B} / \text{WU}_{\text{sole}, B}} = \frac{\text{WUE}_{\text{int}, A} + \text{WUE}_{\text{int}, B}}{\text{WUE}_{\text{sole}, A} + \text{WUE}_{\text{sole}, B}} \quad (5)$$

where pWERA and pWERB are the partial WERs of $A = \text{pigeonpea}$ and $B = \text{maize}$. $\text{WUE}_{\text{int}, A}$ and $\text{WUE}_{\text{int}, B}$ are the water use efficiencies of pigeonpea and maize in the intercrop, while $\text{WUE}_{\text{sole}, A}$ and $\text{WUE}_{\text{sole}, B}$ are the water use efficiencies of $A = \text{pigeonpea}$ and $B = \text{maize}$ as sole crops. The partial WERs characterize the ratios of production per unit water uptake (WU) in intercropping and sole systems in the same way as the partial LERs characterize the ratios of land use efficiencies in intercropping and sole systems. The explanation of WER is similar to LER in that pWERA may be explained as the relative amount of WU needed to obtain the intercrop yield of species A in a sole stand (i.e., assuming $Y_{\text{int}, \text{pigeonpea}} = Y_{\text{sole}, \text{pigeonpea}}$), and likewise for maize (i.e., assuming $Y_{\text{int}, \text{maize}} = Y_{\text{sole}, \text{maize}}$). WER and LER do not need to be equal. If $\text{LER} > 1$, but $\text{WER} \approx 1$, then an intercropping system is efficient in terms of land area needed, but not in terms of water use. If a cropping system records a $\text{LER} > 1$ and $\text{WER} > 1$, it demonstrates that intercropping needs less land and water. When WER is more than 1, it means there is a higher production per unit water in the intercropping system as compared to sole cropping systems; producing the mixture output in sole cropping systems would then need extra water; how much more (%) is given by $(\text{WER} - 1) \times 100$. Water use in the intercropping system cannot be attributed to a single species alone; it is for the whole cropping system.

2.5. Data Analysis

Rainfall and potential evapotranspiration data were collected from a weather station situated within a 1 km radius of the experimental area. Microsoft Excel 2016 (Microsoft Corporation, Washington, USA) was used to plot rainfall and potential evapotranspiration and generate graphs. Soil water tension, dry aboveground biomass matter, and pod and seed yield were recorded for all the treatments. Analysis of variance (ANOVA) was used on GenStat Release 18.2 statistical software (VSN International Limited, Hemphstead, UK). Where statistical differences were found on dry biomass matter and grain yield (LER, WER and WUE), multiple comparisons using Tukey's honest significant difference was used for mean separation.

3. Results

3.1. Rainfall Distribution

The total amount of rainfall received during the study period was 1343.9 mm. However, there was a huge difference among seasons in terms of rainfall (Figure 1). In the 2016 season, the study site received 590.2 mm, which was lower than the 753.7 mm recorded in 2017. The total rainfall in 2016 was lower as compared to the mean annual rainfall of 900 mm in the study site, while rainfall in 2017 was slightly lower. The highest (5.3 mm)

and lowest (2.0 mm) potential evapotranspiration was recorded in December and June 2016, respectively (Figure 1).

Figure 1. Rainfall and potential evapotranspiration (PET).

3.2. Soil Water Tension

Figure 2 shows the soil water tension for the three soil profiles examined during the trial. Generally, the highest soil water tension was experienced at 20 cm, followed by 50 cm and then 120 cm, which had the lowest soil water tension across all the treatments (except in December 2016 to February 2017 on sole pigeonpea and pigeonpea + maize, which recorded a higher soil water tension as shown in Figure 2f). Soil water tension normally increased in the 20 cm soil profile during dry periods, in addition to soil water abstraction by crops at 50 cm, as evidenced by more fluctuations in both seasons as shown in Figure 2a–d. Dramatic soil water tension drops after rainfall events were evidenced in both 20 cm and 50 cm soil profiles. Soil water tension was generally highest in March and July 2016 across all treatments (Figure 2a,c,e), with sole maize (51.2 and 84.3 kPa) recording the highest tension while sole pigeonpea (29.4 and 51.7 kPa) recorded the lowest tension in the 20 cm profile (Figure 2a). For the 50 cm profile, pigeonpea + maize had the highest soil water tension, while sole maize had the lowest (Figure 2c). This observation corresponded well with the rainfall periods, where the least rainfall was recorded in June in both seasons. The deeper soil profile (120 cm) did not show much response, especially in the 2016 season where a gradual increase in soil water tension was observed from April to July 2016, before it started to gradually decline (Figure 2e).

Figure 2. Soil water tension within treatments (Mz = maize, Pp = pigeonpea, Mz + Pp = maize + pigeonpea) across three soil depths.

3.3. Seasonal Water Use (WU) or Evapotranspiration

Significant difference was observed in total seasonal water use in 2016, where sole pigeonpea and pigeonpea + maize recorded similar values that were higher than sole maize in both seasons (Figure 3). The WU values in 2016 ranged from 342 mm to 576 mm, while in

2017, they ranged from 613 mm to 754 mm. Sole maize recorded the lowest WU values across both years (342 mm in 2016 and 613 mm in 2017) (Figure 3).

Figure 3. Water use in different cropping systems. Treatments are significantly different when their error bars do not overlap.

3.4. Dry Biomass Matter and Grain Yield

Significant differences ($p \leq 0.05$) were observed in aboveground dry biomass matter yield (DBMY), grain yield (GY) and total yield (dry biomass matter + grain yield) between the treatments (Table 3). The highest DBMY was recorded in sole pigeonpea and pigeonpea + maize compared to sole maize in 2016. However, in 2017, sole pigeonpea recorded the highest DBMY as compared to other treatments. The GY of intercropped maize was 800 kg ha^{-1} in 2016, which was 28% lower than that of sole maize. The GY of intercropped pigeonpea was 1222 kg ha^{-1} in 2016 and 1414 kg ha^{-1} in 2017 (Table 3). In terms of total yield (dry biomass + grain), sole maize recorded the least over both seasons, while the maize–pigeonpea intercrop had the greatest yield (Table 3).

Table 3. Biomass matter and grain yield (kg ha^{-1}).

Treatments	2016		2016		Total	2017		2017		Total
	Maize DBMY	Maize GY	Pigeonpea DBMY	Pigeonpea GY		Maize DBMY	Maize GY	Pigeonpea DBMY	Pigeonpea GY	
Mz	1312a	1113b	-	-	2425a	1417a	1208.3NS	-	-	2626a
Pp	-	-	2205b	1283b	3368b	-	-	3821.2c	1221.2NS	5042c
Mz + Pp	1346a	800a	2147b	1222b	5513c	-	-	3356.3b	1414NS	4770b

Mz = maize, Pp = pigeonpea, DBMY = dry biomass matter yield, GY = grain yield. Numbers with similar letters are not significantly different, while those with different letters are significantly different at $p \leq 0.05$ according to Tukey's honest significant test. NS = not significant.

3.5. Land Equivalent Ratio (LER) and Water Equivalent Ratio (WER)

The LER of the agroforestry systems was 1.8 in 2016, indicating a substantial merit in land use efficiency by combining maize with pigeonpea (Table 4). Maize + pigeonpea recorded significantly higher LER (1.8) than sole pigeonpea and sole maize (1.0 and 0.8, respectively) (Table 4). Similarly, the same trend was observed on WER, where maize intercropped with pigeonpea recorded a significantly higher ratio of 1.5 as compared to sole pigeonpea (1.0) and sole maize (0.5).

Table 4. Land equivalent ratio (LER) and water equivalent ratio (WER) on two-cropping systems.

Treatment	LER	WER
Maize	0.8 a	0.5 a
Pigeonpea	1.0 b	1.0 b
Pigeonpea + maize	1.8 c	1.5 c
<i>p</i> -value	<0.001	<0.001

Numbers with the same letters are not significantly different, while numbers with different letters are significantly different at $p \leq 0.05$ according to Tukey's honest significant test.

3.6. Water Use Efficiency

Significant differences ($p \leq 0.05$) were observed in terms of WUE. Maize + pigeonpea recorded the highest value in 2016. In 2017, sole pigeonpea recorded a significantly higher WUE than the other treatments (Table 5).

Table 5. Water use efficiency for sole maize, sole pigeonpea and pigeonpea intercropped with maize.

Treatment	Water Use Efficiency (kg mm ⁻¹)	
	2016	2017
Maize	6.1 a	4.3 a
Pigeonpea	7.4 b	6.7 c
Pigeonpea + maize	9.4 c	6.3 b
<i>p</i> -value	0.002	<0.001

Numbers with the same letters are not significantly different, while numbers with different letters are significantly different at $p \leq 0.05$ according to Tukey's honest significant test.

4. Discussion

Soil water tension (SWT) changes are normally affected by rainfall. During the study period, low SWT values were observed during rainfall events; Bullied and Entz [57] also found a similar tendency of low SWT during rainfall events. The lowest amount of soil water stored in the 20 cm profile in each treatment was recorded in June 2016, and June and July 2017, which coincided with the low rainfall amounts received in those months. Furthermore, variations were more prominent on the 20 cm soil layer, which might have been attributed to water abstraction by crop and evaporation. These results agree with those of Asbjornsen et al. [48] and Wang et al. [49], where most water uptake by crops was observed in the 0–50 cm soil profile. Also, since water does not settle in one profile of the soil but moves further down, more water was anticipated at the 120 cm depth, which did not respond much to rainfall events and remained saturated. Seasonal variability had an effect on the WU values experienced during the study period. WU values observed in 2017 were approximately 1.3 times higher in treatments containing pigeonpea and 1.8 times higher in sole crops than those recorded in 2016. Our study agrees with Lenga [58], who reported differences in WU values in different seasons. Pigeonpea + maize and sole pigeonpea recorded similar values of WU, which were higher than sole maize in both seasons. This partly agrees with Chirwa et al. [41] who found no significant differences in WU on agroforestry systems involving maize, pigeonpea and *Gliricidia sepium*.

Kimaro et al. [59], highlighted that in fields with inherently low soil fertility (which is synonymous with the study site), antagonistic nutrient competition might occur between pigeonpea–maize intercropping systems without fertilization. As a result, maize grain and pigeonpea yield under intercropping diminished by 28% and 4.7%, respectively. This might be the reason why our study recorded lower maize grain yield for pigeonpea intercropped with maize than sole maize. Ledgard and Giller [60] highlighted that the benefits of an intercrop system between a legume and cereal crop usually occur to subsequent crops as the leading transfer pathway, because the higher demand for nitrogen by the cereal crop will exert pressure on the legume to fix more nitrogen through BNF, as well as the loss of leaves and root and nodule senescence. For instance, for the maize yield of a sole crop grown subsequent to maize intercropped with pigeonpea in Zimbabwe, pigeonpea was

found to contribute about 25 kg N ha⁻¹ under farmer management without external inputs [61]. Rego and Rao [62] found consistently higher yields of sorghum following sorghum–pigeonpea intercrop. In the same study by Musokwa et al. [63], plots that had previously grown pigeonpea intercropped with grass recorded a two-times greater dry biomass matter yield as compared to sole maize with no fertilizer. However, many studies have found that intercropping can provide a significant yield increase as compared to mono-cropping systems, especially when the component crops have different phenological characteristics [59,64]. These results agree with our study, where the pigeonpea–maize intercropping system yielded higher biomass matter and grain yields as compared to both sole stand crops. Moreover, farmer practices such as land productivity [65], as well as resource use efficiencies such as light, water and nutrients [25,66,67] were also increased in intercropping systems. This study revealed complementarity in water uptake from the upper layer of the soil, however more studies are needed to analyze complementarity in water abstraction from deeper soil layers, especially in the second season where the treatments that contained pigeonpea showed an increase in soil water tension at the deepest layer (120 cm); this might have resulted in higher productivity in an intercropping system than sole maize. Also, better soil coverage, which further reduces evaporation in pigeonpea–maize intercropping systems, might have contributed to higher productivity [68–70]. Water requirements for trees and crops in agroforestry systems are different in time and space. For instance, after maize was harvested, pigeonpea was left behind. Consequently, temporal and spatial complementarities may occur between species. The root systems of component species in intercropping were reported to be established in different soil layers [17,71]. Enhanced WU under different intercropping systems as compared to mono-cropping systems have been reported by various authors [41,72,73].

Higher LER and WER were recorded for the intercropping system, suggesting that growing pigeonpea with maize can lead to the efficient use of both land and water resources that would otherwise not have been utilized. Furthermore, sole pigeonpea had both a higher partial LER and WER as compared to continuous sole maize, possibly because of its drought tolerance. This was also evidenced in the second season, where all treatments containing pigeonpea recorded higher dry biomass matter yield as compared to sole maize. Many authors highlighted that a crop capable of producing higher yields would be expected to have a greater WUE [74–76], this might be the reason for higher the WUE experienced by these treatments than sole maize. Generally, most smallholder farmers in RSA grow sole maize without fertilizer each season. They may integrate it with pigeonpea and be able to get pigeonpea grain (1016–1225 kg ha⁻¹) as shown by this study, which will enable them to avert the risk of total maize crop failure. For example, in other countries such as Malawi and Mozambique, a pigeonpea–maize intercropping system with no fertilizer input has been shown to lower the possibility of crop failure [77–79].

The ability of pigeonpea to grow in harsh environments, combined with a higher BNF, can supply a considerable amount of N to maize-based farming systems in drought-vulnerable areas facing inherent low fertility soils, such as this study site. Only 10% of the total arable land in RSA receives an annual rainfall of more than 750 mm. Despite the technically advanced maize production by commercial farming communities, most smallholder farmers utilize degraded soils located in semiarid environments, which often results in recurrent maize crop failure. Poverty and malnutrition in most rural households have been exacerbated by frequent maize crop failure and nutrient deficiencies. Under these scenarios, pigeonpea could provide a way to enhance the sustainability and profitability of drought-vulnerable cropping systems and to eradicate rural poverty and malnutrition.

5. Conclusions

This study showed that in the first season, pigeonpea can be intercropped with maize without being affected in terms of yield as compared to maize. The agroforestry systems tested in this study resulted in significant improvements in land and water use efficiencies as shown by higher LER and WER. Hence, there is extra production per unit water when

growing pigeonpea + maize as compared to sole cropping systems. To produce the mixed output in mono-cropping systems, they will require 50% more supplementary water according to the WER. Significant differences were found in terms of biomass matter and total yield as compared to sole maize, although grain yield did not differ. This also led to cropping systems which had pigeonpea recording higher WUE than sole maize. Hence, farming systems that include pigeonpea are recommended among smallholder farmers in RSA due to its higher WUE, and its multiple benefits such as its use as human food, livestock feed, replenishing degraded soils and firewood. In case of total maize failure in drought seasons, pigeonpea can provide a source of livelihood.

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