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Ziziphus spina christi for Sustainable Agroforestry Farming in Arid Land of Khartoum State of Sudan

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Abstract

Cow pea (*Vigna unguiculata*) was intercropped with *Ziziphus spina-christi* as summer forage in two consecutive seasons of 2017 and 2018. The aims to find out suitable agroforestry practice for saline soils of Khartoum State. And to investigate effect of tree spacing on forage biomass yield under semi -irrigated systems. Completely randomized block design with 3 replicates was conducted for this trial. Thus *Z.spina-christi* that fixed at 4×4 m was intercropped with cowpea at 1 m and 1.5 m spacing from trees trunk. Tree growth parameters were measured in terms of tree height, tree collar diameter, tree crown diameter and fruit yield per tree. While crop were parameters were determined in terms of plant height, number of plant, forage biomass yield per ha and land equivalent ratio. Soil profile of 1×1 m and 1.5 m depth was excavated and its features were described beside its chemical and physical properties were analyzed for 0-10 cm, 0-30 cm, and 30-60 cm and 60-100 cm layers. The results revealed that soil pH, $CaCO_3$, SAR, ESP, and EC ds/m were increased by increasing soil depths. Meanwhile tree growth in terms of tree height was significant in the first season 2017 when compared with tree collar diameter and tree crown diameter. Also significant differences were recorded for tree growth when compared with sole trees in the second season in 2018. Tree fruit showed marked variations between the two seasons, but it was higher under intercropping particularly at ZS2. Crop plant height was highly significant under sole cropping than intercropping in first season in 2017. In contrast forage biomass yield was significant under intercropping in ZS1 and ZS2 treatments. Land equivalent ratio was advantageous under this agroforestry system particularly under ZS2. Thus it recorded 5 and 9 for ZS2 in the two consecutive seasons respectively. Therefore, it is feasible to introduce this agroforestry system under such arid lands to provide summer forage yield of highly nutritive value and low cost for animals feed as well as to increase farmers' income and to halt desertification and to sequester carbon.

Key Words: agroforestry, cow pea, LER, intercropping, saline soils, *Ziziphus spina-christi*

Introduction

Growing crops between trees is an old agroforestry practice in many African and Asian countries. Thus appropriate agroforestry systems depend on the degree of competition between trees and crops. In effect, trees' characteristic, density and spatial arrangement are the main factors in succeeding any agroforestry system or practice (Nair 1993).

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Hence these are considered as signs of productivity and sustainability of any agroforestry system Rotich et al. (2017). Therefore trees can compensate soils by improving fertility by fixing nitrogen or ameliorating soil physical properties through penetrating trees roots deeply in soil layers (Nair1993; Young 2001). In this respect, many agroforestry practices/systems such as intercropping and alley cropping are well recognized and widely spread. Thus trees and crops were intercropped sequentially or intimately. So, farmers can diversify their crops by getting multiple products from these practices. That can be generated essentially from the trees in terms of timber, fruits, fodders and gum or from field crops in terms of grain yield or biomass. In this regards farmers can safeguard their cropping systems by having multiple benefits and products at various times within the cropping seasons (Nasre Aldin 2010). Besides, farmers will avoid any crops failure or hazards that could occur due to environmental factors. However, some disadvantages can be observed from these intercropping practices in terms of above and below ground competitions. That can be occurred in the available resources in terms of light interception, nutrients and water uptakes as well as allopathic effects (Ong et al. 1996). In addition to some negative effect can be observed due to trees existence in the farms that subject to pests and diseases infestation.

Ziziphus spina-christi is native to vast areas of Africa, extending from Mauritania throughout the Sahara towards Sahelian zones of West Africa and the Red Sea. It is drought hardy and very resistant to heat. It can tolerate mean annual temperature between 19-28°C and elevation limit ranging between 0-2,000 m and mean annual rainfall between 100-500 mm. The tree is frost tender, can withstand water logging for up to 2 months and 8-10 months of dry season. *Z spina-christi* prefers alluvial plains with deep soils and can grow on clay and in saline soils. The tree is an aggressive colonizer, forming spiny impenetrable thickets. Also the tree has many uses for example the branches uses in building houses and fencing. The leave uses as fodder for animals and in local medicine and the fruit is edible (Sahni1968; NAS 1980; Baumer 1983; Elamin1990).

Cowpea (*Vigna unguiculata*) is a summer annual legume that widely spread over all the continents particularly in Africa, Asia and America. It is used in all of its parts for human and animal feed. Thus its seeds have nutritious components such as proteins, carbohydrates, fiber and fats. Besides, cowpea was considered as quality legume hay for livestock feed due to its high digestibility when compared with alfalfa. Cowpea is grown under both irrigation and none irrigated region and performed well under varied soils extended from pH between 5.5 and 6.5. Cowpea can be harvested in period of 60-90 days according to the varieties and its purposes (Davis et al. 1991).

Therefore introduction this intercropping will diversity farmers' crops as well as mitigate any expected hazardous effect that can be occurred as a result of dry spells or climate change. And will halt desertification and to sequester carbon. In this respect, the objectives of this paper were; to find out an agroforestry model that suits saline soils of Khartoum State and to investigate the effect of trees spacing on cowpea crop yield in saline soils.

Materials and Methods

Experimental farm

This experiment was conducted in Forestry and Gum Arabic Research Centre Farm in Soba (Latitude 15° 30' N; Longitude 30° 30' E), south of Khartoum State, Sudan during the wet seasons of 2017 and 2018 on saline soils. The experiment site was classified as Sodic Haplocombids (Elbageer soil series) of the following characteristics; Deep flat, moderately well drained with dark brown over very dark grayish brown soil colour, texture is clay loam over clayey, moderate medium and fine sub angular blocky structure over weak coarse medium and fine sub angular blocky structure over massive, moderately to strongly calcareous soil matrix and soil pH is alkaline. Thus pH is ranging between 7.6, 7.8, 7.9 and 8.6 for the following layers; 0-10cm, 10-30 cm, 30-60 cm and 60-100 cm, respectively. The site constitutes of parts contain $CaCO_3$ concretions and other parts contain salts. Its soluble salts come up to the surface with irrigation and it deposited in the forms of white crystals and incrustations of chlorides and Sulphates of Sodium and Calcium. Land form is flat with slope of 1%.The soil is slightly sticky and plastic wet, with moderate medium and fine sub-angular blocky structure and with few stone. In addition to fine ravels and common sand grains, few $CaCO_3$, grey nodule sand white soft aggregates, few coarse, medium and fine roots for the soil layers as indicated in Table 1, 2.

The area have the following vegetation types; indigenous thorny tree species in terms of desert palm locally known as hegleg (*Balanites aegyptiaca*), Tundub (*Capparis decidua*) and Mesquite (*Prosopis chilensis*) as introduced species. Climate is semi desert, rainfall is 180mm/annum and drainage is moderately well. Temperature ranged between 32°C and 7°C as maximum and low temperature in January respectively. While in May and June the maximum average temperature is 42°C and average minimum is 27°C in July (Bosshard 1966; Daldoum and Ameri 2014).

Field experiment

The materials of the experiment were well established *Ziziphus spina-christi* tree of 5 months old in the first season 2017 under saline soil in the Forestry and Gum Arabic Research Farm in southern of Khartoum State. And cowpea (*Vigna unguiculata*) of improved variety (Ain Algazal) that released by Alobeid Agricultural Research Station in Western Sudan. Completely randomized block design with three replicates were used to implement this experiment. The treatments were; *Z spina-christi* trees as the main factor at spacing of 4×4 m versus cowpea sown at two spacings of 1 m and 1.5 m from the tree trunk, besides controls treatments for both crop and trees. The cowpea was sown at 25 and 50 cm as inter and intra rows spacings respectively (3 seeds per a hole) in the wet seasons of 2017 and 2018 in the first of August. Supplementary irrigation was introduced as necessary in deficiency of rainfall during the growing seasons. Cultural practices in terms of ploughing and weeding were carried out for the cowpea and the trees. The plot size was 12×8 m for each treatment and the total number of the trees per a plot is 12 trees arranged in 3 strips. The experiment site was well protected from any damage that could be occurred by human or animals.

Tree growth parameters

Z spina-christi measurements

Trees were measured in terms of tree height in cm, tree collar diameter in mm and tree crown diameter in m in November before crop harvesting in the two consecutive seasons 2017 and 2018. Also fruit yield was estimated for *Z spina-christi* trees per 3 trees per a plot in grams in November in the two seasons.

Crop parameters

Cowpea parameters were measured in terms of plant height in cm, number of plant per ha and biomass (fresh

Table 1. Soil chemical properties at different depths in the experiment site at soba farm

Depth (cm)	EC (ds/m)	$CaCO_3$ (%)	SAR	ESP	pH paste	N (%)	O.C (%)	C/N ratio
0 -10	2.0	1.8	9	10	7.8	0.810	0.485	6
10-30	2.2	2.1	10	11	8.0	0.820	0.486	6
30-60	2.5	2.3	10	11	8.4	0.830	0.486	6
60-100	16.1	5.2	30	30	9.1	0.820	0.486	6

EC, exchangeable cation; SAR, sodium absorption ratio; ESP, exchangeable sodium percentage; N, nitrogen; O.C, organic carbon.

Table 2. Soluble Cations, Anions, Excl.cal, available P p.pm and CEC at different depths at soba farm

Depth (cm)	Soluble cations			Soluble anions		Excl. cal		Available P (ppm)	CEC
	Na	Ca	Mg	CL	HCO_3	Na	K		
0-10	12.1	8.2	1.8	10.1	1.1	11.3	0.50	2.3	35
10-30	14.2	10.1	2.1	11.3	1.3	11.5	0.55	2.1	36
30-60	17.3	10.6	2.3	13.1	1.3	19.5	0.61	3.4	39
60-100	75.2	12.4	3.1	130.1	3.1	128.1	0.72	1.5	45

EC, exchangeable cation; SAR, sodium absorption ratio; ESP, exchangeable sodium percentage; N, nitrogen; O.C, organic carbon.

forage yield) weight kg/ha at harvest time for the two consecutive seasons in 2017 and 2018.

Land equivalent ratio (LER)

Land Equivalent Ratio (LER) is the Fractions of intercropped crops divided by sole crops was used as indicator for the agroforestry efficiency as indicated by this equation LER=Intercrop1/pure1+intercrop2/pure2+ etc. Therefore, if the value exceeded one, it gives the advantageous of the intercropping system and vice versa if the value is less than one, that expressed mono-cropping system is better than intercropping as stated by Sullivan (1998). The data was calculated for both the crop and the trees for the two seasons 2017 and 2018.

Statistical analysis

Statistical analysis for the tree measurements and crop parameters were determined for the two seasons 2017 and 2018 by using GENSTAT Software. The data means were generated and illustrated in ANOVA Tables, histogram figures and the differences between the trees and crops treatments where explained in terms of LSD (Least Significant Differences at 5% level).

Table 3. *Ziziphus spina-christi* tree height (cm), tree collar diameter (mm) and tree crown diameter (m) in intercropped and control plots in first and second seasons on November 2017 and 2018

Treatment	Tree height (cm)	Tree collar diameter r (mm)	Tree crown diameter (m)
Season 2017			
SZ1	181.6 ± 17.0^{a}	16.2 ± 3.7^{a}	9.00 ± 2.2^{a}
ZS2	207.8 ± 17.0^{a}	19.3 ± 3.7^{a}	4.73 ± 2.2^{a}
Z	127.6 ± 17.0^{b}	10.8 ± 3.7^{a}	3.03 ± 2.2^{a}
Season 2018			
ZS1	240.6 ± 21.0^{a}	33.83 ± 3.0^{ab}	6.65 ± 0.6^{a}
ZS2	238.3 ± 21.03^{ab}	32.17 ± 3.0^{ab}	5.02 ± 0.6^{ab}
Z	200.1 ± 21.0^{c}	24.78 ± 3.0^{a}	3.66 ± 0.6^{c}

Means followed by the same letters are not significantly different at ($p\leq0.05$). ZS1 and ZS2 (*Z.spina-christi* intercropped with cowpea at spacing of 1 m and 1.5 m) from tree trunk. Z, Sole *Z.spina christi*.

Results

Tree growth parameters

Tree height was showed significant difference ($p<0.016$), while tree collar diameter and tree crown diameter did not differ with respect to the intercropping or as sole trees in the first season 2017 as indicated in Table 3. Similaly for trees fruit yield was higher under the intercropped treatments than in the sole tree ones as indicated in Fig. 1. In the second season 2018, varied differences were recorded for tree height, tree collar diameter and tree crown diameter in the intercropped treatments than in the sole trees as indicated in Table 3. Thus tree height was significant ($p<0.05$) under the intercropped treatments . Tree collar diameter was highly significant ($p<0.003$) under the intercropping. Similar result was recorded for the tree crown diameter it was highly significant ($p<0.001$) particularly under ZS1as indicated in Table 3. Also fruit yield per trees was higher under intercropped treatments than in the sole trees as indicated in Fig. 1.

Cowpea parameters

In the first season 2017, cowpea parameters were highly significant for plant height ($p<0.001$) and significant for forage biomass yield ($p<0.05$) as indicate din Table 4.

While in the second season 2018, no significant differences were recorded for the cowpea parameters in terms of plant height, number of plant per ha and crop forage yield (biomass) that recorded ($p<0.07$), but it nearly higher under control treatment than on the intercropped ones as indicated in Table 4.

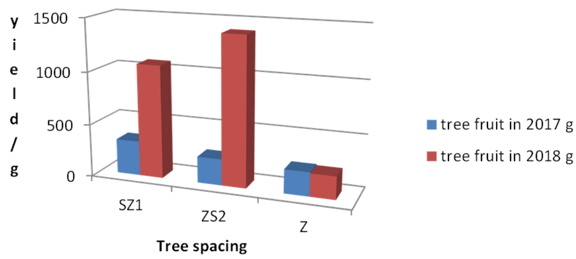

Fig. 1. *Z.spina-christi* tree fruit yield (g) per tree in 2017 and 2018.

Table 4. Cowpea plant height (cm), number of plants /ha and forage fresh yield (kg/ha) intercropped with *Ziziphus spina-christi* and as control in the first and second seasons in 2017 and 2018

Treatment	Plant height (cm)	No. of plant (ha^{-1})	Forage fresh yield ($kg\ ha^{-1}$)	Average biomass yield ($kg\ ha^{-1}$)
Season 2017				
ZS1	11.7±5.1[a]	499,467±182,933.2[a]	1,517±491.9[a]	1,999.5
ZS2	13.8±5.1[a]	723,333±182,933.2[a]	2,482±491.9[a]	
Control	51.8±5.1[b]	506,700±182,933.2[a]	603±491.9[b]	2,332.5
Season 2018				
ZS1	31.9±7.7[a]	1,411,111±3.6[a]	2,867±655.2[a]	2,611.5
ZS2	28.67±7.7[a]	1,266,667±3.6[a]	2,356±655.2[a]	
Control	34.7±7.7[a]	1,788,889±3.6[a]	4,062±655.2[a]	2,332.5

Means followed by the same letters are not significantly different at ($p \leq 0.05$). ZS1 and ZS2 (*Z.spina-christi* intercropped with cowpea at spacing of 1 and 1.5 m) from tree trunk.

Table 5. Land equivalent ratio under intercropping of *Z.spina-christi* in 2017 and 2018

Treatment	forage yield (kg/ha)	Trees fruit yield (kg/ha)	LER
Season 2017			
ZS1	1,517	371.3	4
ZS2	2,482	281.3	5
Sole crop	603	-	
Sole *Z.spina-christi*		255	
Season 2018			
ZS1	2,867	1,375	7
ZS2	2,356	1,750	9
Sole crop	4,062	-	
Sole *Z.spina-christi*	-	217.2	

ZS1 and ZS2 (*Z.spina-christi* spaced at 1 and 1.5 m) from the tree trunk.

Land equivalent ratio (LER)

In the first season 2017 land equivalent ratio (LER) was advantageous for the both treatments but higher under SZ2. Likewise for the second season 2018 but it was substantial under ZS2 as indicated Table 5.

Discussion

Z spina-christi tree growth in terms of tree height was higher under the intercropped treatments in the first season 2017 when compared with the other tree growth, that might be due to favourable site conditions and good cultural practices that undertaken on the intercropped plots. Thus the intercropped plots were subjected to well weeding and watering than the control ones that tendered around the tree roots only. Besides that soil salinity has little effect on *Z.spina-christi* growth. This is in line with some writers such as (Baumer1983; Elamin 1990; Vogt 1995) who reported that *Z spina-christi* is drought resistant and can tolerate some salinity. Despite the fact that the tree growth was in its earlier stage of development and growth. This agreed with Raddad and Luukkanen (2007) who stated that trees growth did not affect in the earlier stage when intercropped with field crops. Meanwhile the variation in the second season, for tree height, tree collar diameter and tree crown diameter under intercropped plots might be also attributed to favourable sites condition besides good tendering as mentioned above. In this respect, the trees were intercropped with leguminous plant namely cowpea that of highly nitrogen fixation rates. In this regard cowpea can form a symbiotic relationship with some soil bacterium that called *Rhizobium* spp.). Therefore this *Rhizobium* can make the atmospheric nitrogen available to the plant which occurs in root nodules of the plant whereas the bacteria utilize sugars that produced by the plant and this it is wide spread world as stated by widely (Davis et al. 1991). On contrary Daldoum and Ameri (2014) reported that tree growth tended to be greater under such soil conditions and at minimal irrigating intervals. In effect soil salinity in this studied area was higher in sub layers depths, but it might be decreased by consistent effect of watering and leaching as shown earlier in our soil profile tables. This in line with Bosshard (1966) who reported that under irrigated saline soil of Khartoum Green belts, salts had come up to the surface due to effect of the irrigation, when pH ranged between 8-9.5.

The variation in tree fruit yield could be attributed to the favourable site conditions and consistent watering under intercropped sites than in control ones as mentioned earlier. As well as to the fact that the intercropped cowpea crop increases soil nitrogen through nitrogen fixation compared to the sole trees.

Meanwhile the significance in plant height in the first season was due to effect of light competition under intercropping when compared with sole crops. In this respect, under sole crop no competition for light was existed. In this regards, in the dry lands the major problems of agroforestry were manifested in competition between herbaceous crops and woody perennials in sharing resources. Thus they appeared to be more, either above or below ground competitions as stated by Ong et al. (1996). Therefore the competition will be more severe at shallow roots' levels for both the trees and the crops. In humid areas competition for above ground resources is found adverse as a result of light interception that affects plant photosynthesis. In this respect, Kessler and Breman (1991) found that the amount of light interception depends on tree characteristics mainly on tree canopy, spacing and species. Therefore they found that sorghum yield decreased by 50% when intercropped with *Parkia bilobosta* in Burkina Faso. Under this study *Z.spina-christi* has tap roots and in its early stage of development, which might probably increase competition with cowpea crop that of the same height and shape.

Meanwhile for the crop biomass yield the significance in the first season might be related to favourable site conditions under intercropped treatments due to consistent watering and good microclimate. In addition to the little effect of competition since *Z.spina-christi* has tap root and has minor interface with cowpea in wider spacing. Davis et al. (1991) reported that cowpea could perform well either under irrigation regimes and different soils types such as minor saline soils as it is drought resistant crop. However, the soil salinity in this experiment site exceeded the threshold which might affect cowpea performance and growth as was shown in the two seasons.

Meanwhile in the second season, the differences under the control plots compared to intercropped plots might be attributed to effect of canopy coverage. Thus the trees in the second season were reached maturity and might have adverse effect on intercropped crops as was shown in tree crown diameter in Table 3. In the regard Marsh et al. (1987) reported that dry matter of 1000 plant of cowpea per acre ranged between 2-5tons/ha, while the average forage biomass yield for this experiment was more in intercropped treatments that amounted to 2 and 3 tons/ha in the first and second seasons respectively compared to 2.3 tons per ha for sole cropping. While other writer such as Taha et al. (2014) found that under favourable conditions of Gezira Scheme of the Sudan other fodder crops such as *Vigna trilobata* crop was yielded 5.4 tons dry matter per ha. Whereas Lablab *purpureus* and *Clitoria ternate* were yielded 4.7 and 5 tons per ha in terms of day matter respectively.

Land Equivalent Ratio (LER) was higher under this agroforestry system particularly in ZS2 spacing for the both seasons due to little effect of intercropping either for crop or forest trees. In this regard, in the first season minor effect of competition for biomass crop yield than for forest fruit was found. Thus LER proportion was amounted to 2.5 and 1.5 for ZS1 and 4.1 and 1.1 for ZS2 for intercropped crop and fruit yields respectively. While in the second season the proportion amounted to 0.71 and 6.33 for ZS1 and 0.6 and 8.1 for ZS2 for forage yields and forest fruit that intercropped respectively. Thus it indicated that the effect of interface of forest tree on forage yield. Generally LER is higher and advantageous under this agroforestry system due to the diversifying crops yield. Other workers were obtained that LER was higher under intercropping systems (Osman et al. 2011; Nasre Aldin et al. 2011; Sanou et al. 2019). Therefore tree fruit can add benefits to the farmers essentially in terms of cash by increasing their income and purchasing power. Besides diversifying farmers' crops and mitigating some environmental hazards.

Therefore it can conclude that intercropping of cowpea as summer forage crop with *Z spina-christi* is feasible under this agroforestry system particularly under wider spacing ZS2. That probably to produce forage yield of low cost and higher protein content to increase farmers' income and maintain their food security as well as to halt desertification and to sequester carbon.

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