Nile Valley University Publications
Nile Journal for Agricultural Sciences (NJAS)
(ISSN: 1585 – 5507)
Volume 09, NO. 01, 2024
https://www.nilevalley.edu.sd

Effect of Alley Cropping Microclimate on Wheat Productivity and Leave Decomposition in a Semi-Desert Region of Northern Sudan

Dalia, A. Arabi[1], Haider E. Shapo[2] and Mohamed A. Adlan[3]

1 Hudeiba Research Station, Agricultural Research Corporation, Ed Damer, Sudan

2 Forest Research Centre, Agricultural Research Corporation, Suba, Khartoum, Sudan

3 Gezira Research Station, Agricultural Research Corporation, Wad Medani, Sudan

Email: daliaarabi22@gmail.com

Abstract

The study was conducted at Hudieba Research Station (Lat. 17.°57′N, 33.°8′E, 300 Km, on a loamy sand soil of the semi-desert region of northern Sudan during 2013 -2015 to examine the effect of alley-cropping system using three N-fixing trees (*Leucaena leucocephala, Sesbania sesban and Sesbania Formosa*) on climatic factors, soil fertility, and to examine the effects of incorporating tree leaves on soil on wheat grain yield in alley cropping system compared to control. The seedlings of the three trees were transplanted in the field in 2011 to establish alleycropping system (8-m wide alleys and 2-m inter rows), the performance of the tree species was assessed as the microclimatic factor and their effect on water use efficiency. Wheat was sown in November two months after incorporating tree leaves earlier in September in RCBD with three replicates and then evaluated for yield and yield components compared to control. Results indicated that the three trees differed in their ability to modify the microclimate with regard to solar irradiance, Formosa being the suitable one. Alleycropping system using Formosa and Sesban trees had good potential in improving water use efficiency compared to Leucaena and control. Nitrogen contents in tree alleys soil much higher in the depth from 0-60cm (309.3, 280.8 and 240.4ppm) for Formosa, Sesban and Leuceana respectively than in control (172.2ppm). Nitrogen content was increased in alley cropping system and in control after incorporating Formosa, Sesban and Leucaena leaves, respectively. Whereas Formosa and Sesban gave higher wheat grain yield (2810, 2513 kg/ha), Leucaena showed the lowest (632 kg/ha) as compared to the control (1759, 1912 and 1776 kg/ha) after incorporating Formosa, Sesban and Leucaena leaves, respectively. It could be concluded that Formosa was a suitable for alleycropping system for the purpose of modifying microclimate and improving crop productivity in semi-desert areas of Northern Sudan. Also All leaves examined in this study were good sources of N for high tress soils which are low in this element.

Keywords: *Leucaena leucocephala, Sesbania sesban, Sesbania Formosa*, microclimate, incorporating, solar irradiance.

تأثيرنظام زراعة ممرات الأشجارعلى المناخ الموضعي وتحلل اوراق الاشجارونموو إنتاجية محصول القمح بمنطقة شبه الصحراء شمال السودان

داليا عبد الحفيظ عربي [1]، حيدر الصافي شبو [2] ومحمد احمد عدلان [3]

1 محطة بحوث الحديبة، هيئة البحوث الزراعية، الدامر، السودان

2 مركز بحوث الغابات، هيئة البحوث الزراعية،سوبا- الخرطوم، السودان

3 محطة بحوث الجزيرة، هيئة البحوث الزراعية، ود مدني، السودان

المؤلف : daliaarabi22@gmail.com

المستخلص

أجريت الدراسة بمحطة بحوث الحديبة شمال السودان في الفترة ما بين 2013-2015م بهدف دراسة إمكانية استخدام ثلاثة أشجار بقولية (الفورموزا – السيسبان – الليوسينا) في نظام الاستزراع الغابي بأتباع نظام زراعة المرات، ودراسة أثر نظام زراعة الممرات على عناصر المناخ وخصوبة التربة وأيضا دراسة أثر دمج أوراق الأشجار في التربة على إنتاجية محصول القمح في ممرات الأشجار مقارنة بالشاهد (المحصول بدون أشجار). تمت زراعة شتول الأشجار في 2011 لإنشاء حقل الاستزراع الغابي في شكل صفوف بعرض 8 متر بين الصفوف و2 متر بين الأشجار بعد ذلك تم تقييم معدل نمو الأشجار كل ثلاث أشهر ودراسة المناخ الموضعي بين صفوف الأشجار وقياس أثر ذلك على كفاءة استخدام المياه. تمت زراعة محصول القمح في نوفمبر بعد شهرين من دفن أوراق الأشجار في المرات والشاهد وتقييم الإنتاج ومكونات الإنتاج لمحصول القمح داخل ممرات الأشجار مقارنة مع الشاهد. وجدت نتائج الدراسة أن الثلاث أشجار تختلف في قابليتها لتغيير المناخ الموضعي فيما يتعلق بنسبة الإشعاع الشمسي وأن الطاقة الشمسية هي أهم عامل يؤثر على إنتاجية المحاصيل حيث وجد أن شجرة الفورموزا اعطت الطاقة الشمسية الأنسب خلال العام. أيضا بينت النتائج أن نظام زراعة الممرات باستخدام أشجار الفورموزا والسيسبان ذو كفاءة عالية في تحسين استخدام المياه مقارنة بشجرة الليوسينا والشاهد. أظهرت النتائج ايضا أن محتوي النيتروجين في تربة ممرات أشجار الفورموزا، السيسبان والليوسينا في العمق 0-60سم أعلي كثيراً (309.3، 280.8 و240.4جزء من المليون) للثلاثة أشجار على التوالي مقارنة بالشاهد (172.2 جزء من المليون). زاد محتوي النيتروجين في التربة في ممرات الأشجار والشاهد بعد دفن أوراق أشجار الفورموزا والسيسبان والليوسنا على التوالي. ايضا أظهرت النتائج أن إنتاجية القمح المزروع في ممرات أشجار الفورموزا والسيسبان مع دفن أوراق الأشجار (2810، 2513 كجم /هكتار) أعلي إنتاجية من المزروع في ممرات الليوسينا (632 كجم /هكتار) مقارنة بالإنتاجية في معاملة دفن أوراق الثلاث أشجار على التوالي في الشاهد (1759، 1912، 1776 كجم / هكتار).خلصت الدراسة الي أن شجرة الفورموزا تناسب نظام الاستزراع الغابي لكفاءتها في تحسين المناخ الموضعين زيادة كفاءة استخدام المياه وزيادة إنتاجية المحاصيل في المناطق شبه الصحراوية في شمال السودان، أن كل أوراق الأشجار التي استخدمت في التجربة ذات مصدر جيد للنتروجين في أراضي التروس العليا ذات المستوي المنخفض لذلك العنصر.

كلمات مفتاحية: المناخ الموضعي، الاشعاع الشمسي، الفورموزا ، السيسبان ، الليوسينا

Introduction

Desertification is one of the major environmental problems in Sudan, which it considered one of the most arid territories in Africa and about 31% of the country's land is hyper-arid, and 63% is dry lands at risk of desertification (Ayoub, 1998). Desertification in the Northern Sudan is a very serious problem threatening not only the agriculture land base, but also the stay of the inhabitants of the area who depend mainly on agriculture for their livelihood. Planting woody trees could play a protective and productive role in the Northern Sudan. However, there are some obstacles hindering the development of a forestation programme in the area, such as the high cost of irrigation water and lack of short-term incentive until the trees become economically valuable. In addition, farmers believe that the integration of woody species in their farms would adversely compete with the associated crops. Thus the challenge of sustainable land-use intensification requires the integration of trees into the farming system to achieve a range of social, environmental and economic objectives at the same time. Alley cropping is one of the methods of integrating trees in agricultural land (agroforestry system). According to the recent FAO's definition in HLPE, (2017); Agroforestry is defined as a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. The combination of trees and crops can be done in different temporal and spatial sequences, e.g. alley cropping, intercropping, hedgerow systems and improved fallows (Sharma *et al*., 2016). Because of their ability to provide economic and environmental benefits, agroforestry interventions are considered to be the best way to minimize the impacts of climate change through improving microclimate, soil fertility and water use, as well as diversification of the agricultural systems. Alley cropping, using N-fixing trees, is sought a potential production practice that can provide several conservational and production benefits in the study area (Shapo, 2006). Trees used in agroforestry systems are mainly leguminous because of their ability to fix nitrogen especially in the arid and semi-arid regions where fertilizer use is not economically feasible (Van Noordwijk and Ong, 1999). Application of plant residues to the soil surface has widely been used in the semi-arid tropical agriculture and agroforestry. These nutrients become available to crop through decomposition of the tree pruning and litter.

The main objective of this study was to examine the potential of agroforestry system in combating desertification, improves and sustains crop productivity. The specific objectives were to examine the effect of alley-cropping system on climatic factors, water behaviour and to examine the effects of incorporating tree leaves on soil on wheat grain yield in alley cropping system compared to control.

Materials and methods

The experiments were conducted at Hudeiba research station, (Lat. 17. °57′N, 33. °8′E, 300 Km north of Khartoum, Sudan). The study area lies within semi-desert region with mean range annual rainfall of 0 -100 mm. The summer season was characterized by low humidity and high temperature. The soil generally is alkaline (pH 8 to 8.4), non-saline, non-sodic with very low organic carbon and total N. The percentage of Ca CO_3 increases with depth.

Three month old seedlings (55-60cm in height for Leucaena and Sesban, 30-35cm for Formosa tree) were transplanted in July 2011for establishing the agroforestry farm. Trees were planted at 2m intra row spacing and 8 m inter row spacing and was arranged in an east-west direction.

Air dried leaves (156g/m^2) from each tree was incorporated in the top soil in the middle of September and it was irrigated every 10 days. Then wheat crop *(Triticum aestivum L.)* variety Neelain was sown in middle of November (2013-2014) in these different plots, land preparation of each plot was done manually. Wheat was sown at a seed rate of 120kg/ha in lines 20cm apart. Nitrogen fertilizer was added at a rate of (86kg N/ha) as urea in two split doses after second and fifth irrigation. Weeds were controlled manually.

Data collection

Tree performance

Height, diameter at breast height (dbh) (at 1.3 m above ground), diameter at 10 cm above the ground level (dbase), number of branch and dry weight of branches and leaves were done to assess the performance of the three tree species. The diameters were measured using caliper.

Tree metrological data

These data covered maximum temperatures, humidity and solar radiation at three zones of the alley. Thermometers were used to measure maximum temperatures, while wet and dry-bulb thermometers were used to determine humidity. Tube solarimeters (Delta-T TSL, 85.8 × 2.2 cm, sensitive to solar radiation of 0.35 to 2.5 um) coupled with microvolt integrators (Delta-T) were used for measuring incoming radiation. They were placed at ground level across the three zones of the alley and the control plot. Measurements were taken three times a day

(9:00, 12:00 and 16:00 Local Time) at 10-day intervals Average monthly values were accumulated to obtain seasonal values in the control plot and in each alley zone.

Crop parameters

Plant samples were taken at harvesting time from an area of one squire meter in the center, southern and northern alleys and control plots to determine wheat grain yield (kg/ha) and yield components (plant height (cm), number of spike/m^2, thousand grain weight, number of grain/spike and spike height).

Soil analysis

Soil analysis was done at the laboratory of soil and water research department of Hudieba Research Station (HRS). The samples from soil sites were taken for analysis of NPK and O.C. ,from different tree alleys and control plots from three depths (0-20, 20-40 and 40-60cm) before incorporating tree leaves and from the depth of 20cm after leaves incorporation.

Measurement of Applied water and Soil Moisture Content

The average of the applied irrigation water (m^3) was measured directly in the field by a current meter using the following equation:

$I = A \times T \times V$. Where, I = applied irrigation water (m^3), A = cross section area (m^2), T = total time (s) and V = velocity (m s^{-1}) which was derived from the equation: $V = 0.008 + 0.2667n$

Where, n = revolutions per second (rev s^{-1}) obtained from the formula

$$n = \frac{\text{number of pulse counts}}{\text{times in second}}$$

Soil moisture was measured gravimetrically at depths of 15, 30, 45cm, just before subsequent irrigation. Soil samples were dried at 105 °C for 24 hours and soil moisture calculated on dry weight basis.

Statistical Analysis:

Statistical analysis was done according to standard statistical methods using GENSTAT statistical package.

Results

Performance of the three tree species

There were highly significant differences (*P* = 0.001) among the different trees in terms of plant height, dbh and dbase (Table 1). Formosa and Leucaena had significantly higher air dry weight of leaves, while Sesban showed the lowest one.

Table 1. Performance of the three tree species.

Treatments	Measurement (cm)			Number	Air dry weight (kg)	
Tree species	**Height**	**Dbh**	**dbase**	**Branches**	**Branches**	**Leaves**
S.formosa	683	13.7	21.4	22.0	54.5	2.7
S.sesban	511	6.0	21.9	27.3	27.0	0.49
L.leucocephala	720	7.5	10.5	43.3	22.8	1.93
Sig	***	***	**	**	*	*
S.E	7.69	0.50	0.59	1.4	2.7	0.26
C.V%	2.09	9.59	6.8	8.0	13.5	26.6

dbh, diameter at breast height, dbase, diameter at 10 cm above the ground level.

*, **, *** Significant at $p \leq 0.05$, 0.01 and 0.001 respectively

Microclimatic Modification

Table 2a and 2b showed that during the crop season, the modification on solar irradiance in tree alleys was 53.6, 45.5 and 67.6% of control for Formosa, Sesban and Leucaena alleys respectively (this equals a reduction of 46.4, 54.5 and 32.4% in solar irradiance in the three tree alleys respectively), while the maximum temperature was reduced by 1.2, 1.1 and1.2°.

The relative humidity was increased by 11.3, 9.3 and 11.8% for Formosa, Sesban and Leucaena alleys respectively.

Table 2a Irradiance of the tree alleys as a percentage of control in 2013-2014.

	S.formosa		*S.sesban*		*L.leucocephala*		control
(Seasons)	kw m−2	S.f/cont	kwm−2	S.s/cont	kwm−2	L.l/cont	kwm−2
November	0.119	42.7	0.099	35.5	0.195	69.6	0.279
December	0.099	39.7	0.079	31.7	0.190	76.3	0.249
January	0.162	53.1	0.126	41.3	0.193	63.3	0.305
February	0.165	50.3	0.132	40.1	0.200	61.0	0.328
X(Winter)	0.136	46.4	0.108	37.2	0.195	67.6	0.290

Table 2b Average variation in maximum temperature and relative humidity in the alleys as differences from the control (2013-2014).

	Maximum temperature (°C)				**Relative humidity (%)**			
(Seasons)	*S.formosa*	*S.sesban*	*L.leucocephala*	Control	*S.formosa*	*S.sesban*	*L.leucocephala*	co
November	-0.9	-1.1	-1.0	34.3	18.5+	18.3+	20+	
December	-2.0	-2.0	-2.1	32.9	15+	17+	17+	
January	-1.4	-1.4	-1.3	30.5	10+	11+	12+	
February	-1.4	-1.4	-1.6	31.7	8+	9+	11+	
X(Winter)	-1.4	-1.5	-1.5	32.4	12.9+	13.8	15+	4

Amount of water applied and Soil moisture content

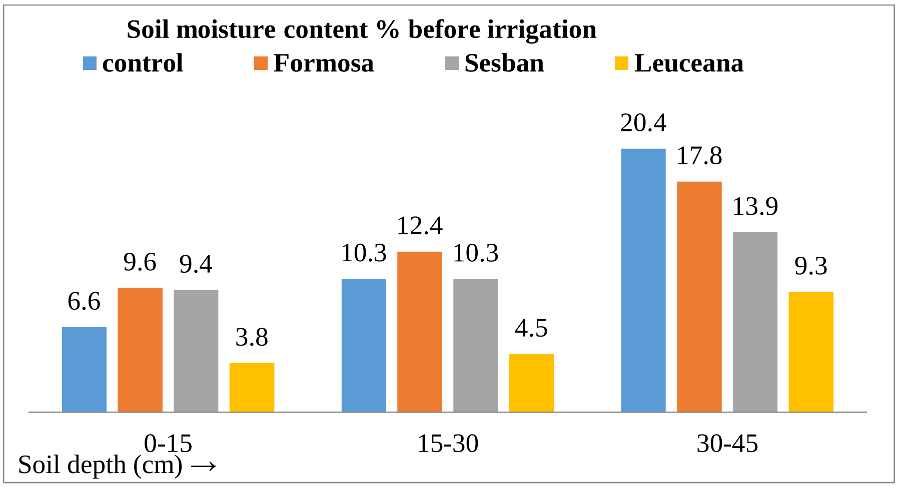
There were significant differences in water consumption by the three tree species (Table 3.). Wheat crop under Formosa and Sesban Alleys consumed less water compared to control and Leucaena. The highest amount of saved water shown under Formosa alley while the lowest value under Leucaena.

Formosa and Sesban alleys gave the highest moisture content in the 0-15 cm depth compared to Leucaena alley and control (Figures.1). Also Formosa alley gave higher soil moisture content in 15-30cm zone compared to the other two species and control. Leucaena alley gave the lowest soil moisture content.

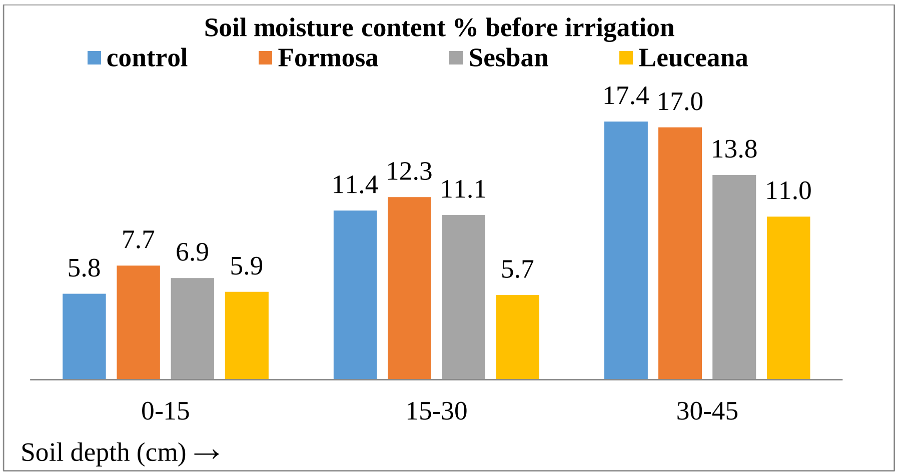
Table 3. Amount of water applied (m^3ha^{-1}) and water saved as percentage of control in alley cropping for wheat crop.

Months	November	December	January	February	Average	%water saved
Control	933.8	1153.5	1020.4	1128.8	1059.1	
S.formosa	729.0	886.9	783.5	931.3	832.7	**21.4**
S.sesban	854.1	910.2	927.8	1105.2	949.3	**10.4**
L.leucocephala	923.3	1191.5	1156.2	1210.1	1120.3	**- 5.8**
Sig	**	***	***	***		
S.E±	28.5	25.6	39.4	33.3		
C.V%	6.6	4.9	8.1	6.1		

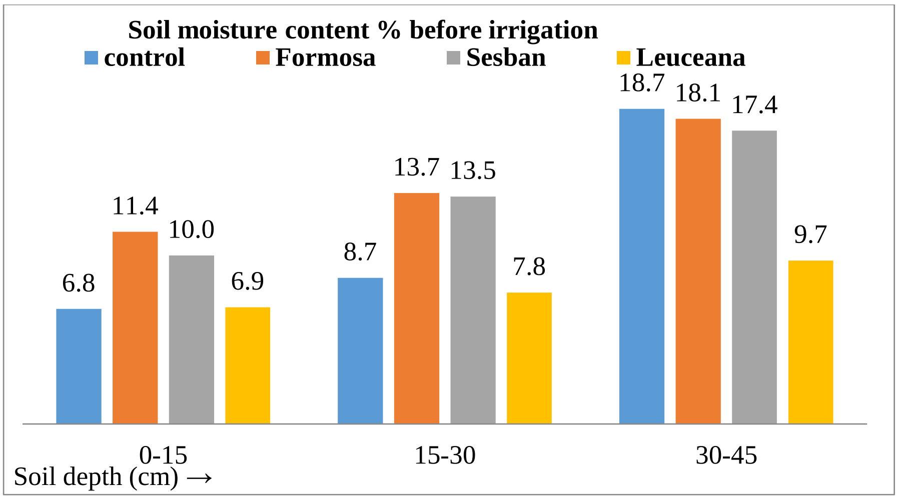
Sig.L **, *** Significant at $p \leq 0.01$ and 0.001 respectively



December



January



February

Figure 1. Residual soil moisture content at three wheat growth stages in the tree alleys compared to control

Nitrogen and organic carbon content in the Soil

There were highly significant differences (*P*=0.001) between alley cropping system and control in soil nitrogen and organic carbon contents. Higher nitrogen was found under alley cropping system (349.9) ppm compared to control (193.4 ppm).

Generally, there were significant differences (*P*=0.001) in soil nitrogen and organic carbon contents before and after incorporating tree leaves in ally cropping system and control. Before incorporating tree leaves Soil nitrogen content was 232.3 ppm and organic carbon contents was 0.154%, nitrogen increase after incorporating tree leaves (311.7ppm), and organic carbon contents was 0.188%. The results showed that incorporating Formosa, Sesban and Leucaena leaves increased Nitrogen soil content by 34.4, 62.1, and 32.8% in alley cropping treatments and by 14.4, 27.9 and 14.6% in control for Formosa, Sesban and Leucaena leaves, respectively.

Effect of ally cropping system on Wheat grain yield

Analysis of variance revealed that wheat grain yield was significantly affected by alley cropping system. Table (6) showed that there were highly significant ($P < 0.001$) differences between various treatments in terms of yield and yield components of wheat crop under tree alleys compared to control plot. In direct sun (100% light intensity) there were no significant differences between wheat grain yield after incorporating Formosa, Sesban and Leucaena leaves. In alley cropping system after incorporating leaves, Formosa and Sesban trees increased yield of wheat grain yield by 60 and 31% respectively, while it was reduced in Leuceana alley by 64% compared to control.

Table 4. Effect of tree species and soil depths (0-60cm) on soil nitrogen, organic carbon, phosphorus and potassium contents.

Treatments	Nitrogen(ppm)	O.C(%)	P(ppm)	K(ppm)
Tree species				
S.formosa	309.3	0.163	1.34	0.460
S.sesban	280.8	0.154	1.30	0.432
L.leucocephala	240.4	0.141	1.54	0.507
Control	172.2	0.129	1.12	0.434
Sig.L	***	**	***	Ns
S.E±	9.0	0.004	0.034	0.024
Soil depths(cm)				
20cm	262.7	0.161	1.5	0.518
40cm	257.5	0.141	1.34	0.422
60cm	231.9	0.138	1.29	0.436
Sig.L	***	**	**	**
S.E±	3.7	0.005	0.03	0.016
Effect of tree species and soil depths				
***S.f* x 20cm**	333.3	0.173	1.43	0.543
40cm	326.7	0.167	1.37	0.383
60cm	268.0	0.151	1.23	0.453
***S.s* x 20cm**	282.7	0.172	1.40	0.480
40cm	283.3	0.141	1.30	0.403
60cm	276.3	0.149	1.20	0.413
***L.l* x 20cm**	248.0	0.160	1.77	0.537
40cm	249.0	0.130	1.4	0.493
60cm	224.3	0.135	1.4	0.490
Co x 20cm	180.7	0.140	1.10	0.510
40cm	171.0	0.128	1.13	0.407
60cm	159.0	0.119	1.13	0.387
Sig.L	10.9	0.01	0.07	0.04
S.E±	*	Ns	Ns	Ns
C.V%	5.1	10.8	9.0	12.2

Ns: Not significant. *, **, *** Significant at p ≤ 0.05, 0.01 and 0.001 respectively. *S.f, S.formosa*, *S.s*, *S.sesban*, *L.l*, *L.leucocephala*.

Table 5. Nitrogen and organic carbon contents in alleycropping system and control before and after incorporating tree leaves in the 0-20cm soil depth.

Leaves treatments			Soil treatment			Alleycropping and control		
Leaves	**N (ppm)**	**O.C (%)**		**N (ppm)**	**O.C (%)**		**N(ppm)**	**O.C (%)**
S.f	290.6	0.178	**Bef.lea**	232.3	0.154	**Control**	193.4	0.154
S.s	286.7	0.173	**Aft.lea**	311.1	0.188	**Alley**	349.9	0.189
L.l	237.8	0.163	-	-	-	-	-	-
Sig	***	*		***	**		**	*
S.E±	5.0	0.006		3.5	0.003		5.0	0.006

Effect of different leaves on N and O.C in soil after and before incorporating tree leaves

		Bef.incor.Leaves		Aft. incor.Leaves	
Leaves	**Treatments**	**N (ppm)**	**O.C (%)**	**N (ppm)**	**O.C (%)**
S.f	**Control**	177.7	0.143	203.3	0.169
	Alley	333.3	0.173	448.0	0.219
S.s	**Control**	178.0	0.136	227.7	0.176
	Alley	282.7	0.172	458.3	0.217
L.l	**Control**	174.3	0.142	199.7	0.157
	Alley	248.0	0.160	329.3	0.193
Sig		*	Ns		
S.E±		8.3	0.008		
C.V%		5.4	6.2		

*P = 0.01; ** P = 0.001; *** P = 0.0001, Ns=Non significant. Bef.incor.Leaves . Before incorporating leaves. Aft.incor . After incorporating leaves. N: Nitrogen .O.C: Organic Carbon. *S.f, S.formosa*. *S.s, S.sesban*. *L.l, L.leucocephala*

Table 6. Yield and yield component of wheat grown after incorporating three tree leaves in alley cropping system compared to control.

Light intensity	Yield (kg/ha)	plant height (cm)	No.spike /m²	Wg.1000s (g)	Spike length (cm)	Seeds/spike
100%	1816	65.3	347	35.2	6.9	30.2
50%	1985	69.1	348	33.2	6.2	28.1
Sig.L	Ns	Ns	Ns	Ns	*	Ns
S.E±	42.4	1.8	9.6	1.06	0.20	0.82
Tree leaves						
S.f	2284	72.0	359	36.4	7.2	32.9
S.s	2212	71.7	353	36.0	7.0	32.6
L.l	1204	57.9	332	30.2	5.5	22.0
Sig.L	***	**	Ns	***	**	***
S.E±	50.4	2.21	11.8	1.30	0.24	0.54
Effect of light intensity and tree leaves						
100%x *S.f*	1759	65.0	352	35.8	7.2	30.1
S.s	1912	66.8	347	34.9	7.0	32.6
L.l	1776	64.0	343	34.8	6.4	27.8
50%x *S.f*	2810	79.0	365	36.9	7.1	35.6
S.s	2513	76.6	358	37.0	7.0	32.6
L.l	632	51.7	322	25.6	4.6	16.2
Sig.L	***	**	Ns	**	*	***
S.E±	72.0	3.12	16.7	1.84	0.34	1.41
CV%	6%	8%	6%	7%	9%	8.4%

Ns: Not significant. *, **, *** Significant at $p \leq 0.05$, 0.01 and 0.001 respectively. *S.f*, *S.formosa*, *S.s*, *S.sesban*, *L.l*, *L.leucocephala*.

Discussion

Alley cropping system with the suitable selected trees has proven to be suitable for microclimate improvement and modification, water use efficiency and soil nutrient availability; hence, they had positive impact on increasing crop productivity. According to results obtained in these experiments, the tree component in the system play the greatest role in improving microclimatic conditions, water use, soil nutrients status, and thus wheat grain yield. There is good experimental evidence that a suitable choice of agroforestry systems may enhance system productivity by increasing the use of available resources (Ong and Huxley; Ong *et al*., 1996, 2006).

The aboveground interaction regarding microclimate modification and water use had confirmed the previous findings obtained out in Hudieba Research Farm in spite of the fact that the tree species used previously differ from ours; Shapo and Adam (2008) reported that in the same area solar radiation is the most influential factor responsible for yield reduction or increase in alley cropping system. In addition, the reduction in solar radiation and wind speed reduced evapotranspiration and thereby water use of crop plants. Ivezi´c *et al.* (2021) reported that trees mitigate microclimatic extremes, creating more stable environmental conditions for understory species, and avoiding heat stress.

In this study the amount of intercepted light in the alleys of the three tree species depends mainly on tree structure (height and general growth character of the tree), that affected the performance and the yield of the crops. Formosa showed high suitability in alley-cropping system and gave the highest wheat grain yield this because of its capacity to transmit sufficient amount of light through the canopy. This agreed with Shapo and Adam (2008) who reported that in the same area of the study *A. stenophylla* alley with its relatively higher average radiation (62% of the control) remarkably increased the economic yield of both groundnut and sesame by 37.7 and 40.3%, compared to the control, respectively. Also this result agrees with Jose *et al*. (2004) who reported that the most noticeable aboveground interaction is the competition for light between the specie.

Alley cropping system has a good potential in improving water use efficiency compared to mono-cropping systems. The saved water was much higher in alley-cropped plots than in control one, because the reduction in solar radiation and wind speed resulted in lower evapotranspiration and therefore less water use by crop plants, Ellison *et al*. (2017) mention that trees improve the microclimate by shading crops and cooling the surrounding air by increasing the transpiration rate. Formosa-alley affected the below-ground interactions positively since it had surface lateral roots, which was subjected to regular root pruning due to land preparation for seasonal crops, so it reduced root competition each growing season in the soil depth between 15-30cm resulting in the highest water saving in this zone.

Nitrogen and organic carbon content in the Soil

Higher nitrogen was found under alley cropping system due to the, nitrogen fixation and the high quantity of the different tree residues and the continues addition of leaf litter and other tree components such as roots, floors, etc . Pinho *et al.*, (2012) showed that When their leaves fall, more nutrients are reintroduced to the soil, and this process, which is often most productive in native forests, can be replicated by introducing diverse tree species into agricultural systems

Wheat grain yield in tree alleys compared to control

Alley cropping system with the suitable tree species had positive impact on crops yield. Within the alley cropping system, the result was a little bit complicated due to the complicated intermingled interactions of the above and the below ground interaction, which is so difficult to separate the effect of each climate factors or soil behaviour. However, Formosa tree optimize the microclimate and saved the water, in addition, there was contentious addition of leaves that might increase the soil nitrogen content, therefore Formosa alley effects gave the highest wheat yield. Sesban alley gave higher wheat yield compared to control and relatively similar to Formosa alley, that possibly of its high leaves nitrogen content and high rate of decomposition compared to the other two species (Dalia *et al*., 2020). Shapo (2008) found that the average yield in the alley plots increased over control by 69, 15, and 10% for wheat, faba bean, and common bean, respectively. Also in a review summary of 94 studies from Sub-Saharan Africa, Akinnifesi *et al*. (2010) concluded that using nitrogen-fixing trees increased yields up to several hundred per cent and significantly improved food security

The lowest yield of the wheat crop in Leucaena tree alleys might be due to its high aggressive competition for water (underground competition) and due to the high incoming radiation in the alley (aboveground competition). These results were similar to those of Govindarajan *et al.* (1996) who found that alley cropping involving *Leucaena leucocephala* greatly reduced crop yield because competition for water outweighed the benefits of improvements in soil fertility resulting from applications of green leaf manure, nitrogen fixation and increased root turnover.

This result also agreed with Ong *et al.* (2000) who showed that in the semi-arid tropics, the competition for water and nutrients severely reduced maize yields when grown with *Grevillea robusta*. Furthermore, Kuyah *et al*. (2016) found many studies confirming that competition between trees and crops could be minimised by selecting non-competitive species as well as pruning the roots and the canopy.

Conclusions

- Alleycropping system using N-Fixing trees is a suitable technology for increasing crop yield through improving microclimate, water use, and soil nutrient status.
- Although it is difficult to separate between above and below ground interaction of trees in agroforestry system, there were positive effects of these interactions in all the system and in overall yield.
- The application of the N-fixing tree leaves in the soils that are deficient in N will improve soil nutrient status.

References

Akinnifesi, F.K.; Ajayi, O.C.; Silechi, G.; Chirwa, P.W.; Chianu, J. (2010). Fertiliser trees for sustainable food security in the maize-based production systems of East and Southern Africa. Agronomy in Sustainable Dev. 30: 615–629

Ayoub, Ali Taha. (1998). Extent, severity and causative factors of land degradation in the Sudan. Journal of Arid Environments 38 (3): 397-409.

Dalia, A.A.; Shapo, H.; Adlan, M. (2020). Effect of Alleycropping Microclimate on Litter Decomposition and Yield of some Field Crops in Northern Sudan. Ph.D. Thesis. Sudan Academy of Sciences, Sudan.

Ellison, D.; Morris, C.E.; Locatelli, B.; Sheil, D.; Cohen, J.; Murdiyarso, D.; Gutierrez, C.; Noordwijk,. Van M.; Creed, I.F.; Pokorny, J.; Gaveau, D.; Spracklen, D.V.; Bargués Tobella, A.; Ilstedt, U.; Teuling, A.J.; Gebrehiwot, S.G.; Sands, D.C.; Muys, B.; Verbist, B.; Springgay, E.; Sugandi, Y. ; Sullivan, C.A. (2017). Trees, forests and water: Cool insights for a hot world. Global Environmental Change. 43: 51–61.

Govindarajan, M., Rao, M.R., Muthuva, M.N. and Nair, P.K. 1996. Soil water and root dynamics under hedgerow intercropping in semi-arid Kenya. Agronomy Journal 88: 513-520.

HLPE (High Level Panel of Experts on Food Security and Nutrition). (2017). Sustainable forestry for food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome.

Ivezi´c V; Yu Y; Werf Wvd (2021) Crop Yields in European Agroforestry Systems: A Meta-Analysis. Front. Sustain. Food Syst. 5:606631. doi: 10.3389/fsufs.2021.606631

Jose, S.; Gillespie, A.R.; Pallardy, S.G. (2004). Interspecific interactions in temperate agroforestry. In Agroforestry Systems. pp. 237–255. Available at: http://link.springer.com/10.1023/B:AGFO.0000029002.85273.9b [Accessed May 2, 2017].

Kuyah, S.; Öborn, I.; Jonsson, M.; Dahlin, A.S.; Barrios, E.; Muthuri, C.; Malmer, A.; Nyaga, J.; Magaju, C.; Namirembe, S.; Nyberg, Y.; Sinclair, F.L. (2016). Trees in agricultural landscapes enhance provision of ecosystem services in sub-Saharan Africa. International Journal of Biodiversity Science, Ecosystem Services and Management. 12(4): 255-273.

Ong, C.K.; Huxley P. (1996). Tree-Crop Illteractions- A Physiological Approach. CAB International, Wallingford, UK. 386 p.

Ong, C.K.;Black, C.R.; Muthuri, C.W. (2006). Modifying forests and agroforestry for improved water productivity in the semi-arid tropics. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 65: 1-19.

Ong, C.K.; Black, C.R.; Wallace, J.S.; Khan, A.A.H.; Lott, J.E.; Jackson, N.A.; Howard, S.B.; Smith, D.M. (2000). Productivity, microclimate and water use in Grevillea robusta-based agroforestry systems on hills lopes in semi-arid Kenya. Agriculture, Ecosystems and Environment 80: 12I -14 I.

Pinho, R. C.; Miller R. P.; Alfaia, S. S. (2012). Agroforestry and the Improvement of Soil Fertility: A View from Amazonia. Report. Applied and Environmental Soil Science 2012, Article ID 616383..https://www.hindawi.com/journals/aess/2012/616383/.

Shapo H.; Adam H. (2006). Effects of alley-cropping systems on crop productivity and water use efficiency in semi-desert region of Northern Sudan. In: Asch, F. & Becker, M. (eds) Prosperity

Shapo, H.; Adam, H. (2008). Modification of Microclimate and Associated Food Crop Productivity in an Alley-cropping System in Northern Sudan. In Toward Agroforestry Design, chapter 7: 98-109.

Sharma, N.; Bohra, B.; Pragya, M.; Cianella, R.; Dobie, P.; Lehmann, S. (2016). Bioenergy from agroforestry can lead to improved food security, climate change, soil quality, and rural development. Food and Energy Security. 5(3):165-183.

Van Noordwijk, M.; Ong, C.K. (1999). Can the ecosystem mimic hypotheses be applied to farms in African savannahs? Agroforestry systems 45: 131-158.