Journal of Environmental Biology
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November 2010, 31(6) 987-993 (2010)

Growth, biomass production and photosynthesis of *Cenchrus ciliaris* L. under *Acacia tortilis* (Forssk.) Hayne based silvopastoral systems in semi arid tropics

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(Received: September 07, 2009; Revised received: February 10, 2010; Re-revised received: March 12, 2010; Accepted: April 20, 2010)

Abstract: *The growth, biomass production and photosynthesis of Cenchrus ciliaris was studied under the canopies of 17 yr old Acacia tortilis trees in semi arid tropical environment. On an average the full grown canopy of A. tortilis at the spacing of 4x4 m allowed 55% of total Photosynthetically Active Radiation (PAR) which in turn increased Relative Humidity (RH) and reduced under canopy temperature to -1.75^{o}C over the open air temperature. C. ciliaris attained higher height under the shade of A. tortilis. The tiller production and leaf area index decreased marginally under the shade of tree canopies as compared to the open grown grasses. C. ciliaris accumulated higher chlorophyll a and b under the shade of tree canopies indicating its shade adaptation potential. The assimilatory functions such as rate of photosynthesis, transpiration, stomatal conductance, photosynthetic water use efficiency (PN/TR) and carboxylation efficiency (PN/CINT) decreased under the tree canopies due to low availability of PAR. The total biomass production in term of fresh and dry weight decreased under the tree canopies. On average of 2 yr C. ciliaris had produced 12.78 t ha^{-1} green and 3.72 t ha^{-1} dry biomass under the tree canopies of A. tortilis. The dry matter yield reduced to 38% under the tree canopies over the open grown grasses. The A. tortilis + C. ciliaris maintained higher soil moisture, organic carbon content and available N P K for sustainable biomass production for the longer period. The higher accumulation of crude protein, starch, sugar and nitrogen in leaves and stem of C. ciliaris indicates that this grass species also maintained its quality under A. tortilis based silvopastoral system. The photosynthesis and dry matter accumulation are closely associated with available PAR indicating that for sustainable production of this grass species in the silvopasture systems for longer period about 55% or more PAR is required.*

Key words: *Acacia tortilis, Biomass, Cenchrus ciliaris, Chlorophyll, Nutrient, PAR, Photosynthesis, Silvopasture system*
PDF of full length paper is available online

Introduction

The development of wastelands through the establishment and management of silvopasture not only checks land degradation forces but also facilitates the production of human and animal needs and conservation of biodiversity and natural resources. In tree-crop intercropping systems, the component crops interact with each other through the interaction of environment factors causing responses on plant functions which intern affect the sustainability of the system. The growth of trees and crops in such system depends upon their relative ability to tap the available resources such as light, water and nutrients and then interact to sub optimal levels of these resources (Conner, 1983). If water and mineral nutrient are plentiful then light is the main environmental resource limiting plant productivity. The silvopastoral systems have been studied for their advantage over existing agricultural practices for their growth and productivity (Deb Roy and Pathak, 1983; Pathak and Roy 1994; Pathak *et al.,* 1995; Grewal *et al*., 1996). The physical parameters such as air and canopy temperature, light transmission, relative humidity, soil temperature, soil moisture and energy balance are the important factors influencing the growth and assimilatory functioning of the under canopy crops in the silvopasture system (Hazra, 1985; Pathak and Bhatt, 2003; Wu and Dalmacio, 1991). Light is the major limiting factor for the growth of understory vegetation in agroforestry system (Basavraju *et al*., 2001; Peri *et al*., 2007; Reynolds *et al*., 2007). Although much work has been done on the production aspects of grasses in the silvopastoral system but little information is available on tree-crop interaction with respect to micro-environmental changes and physiological processes of the grasses under tree canopies in the silvopasture systems. Therefore, the major thrust in this programme was on the investigation of micro-environmental changes in the system, growth behavior, productivity, assimilatory processes and quality attributes of the *Cenchrus ciliaris* under *Acacia tortilis* based silvopastoral system in the semi-arid tropical region.

Materials and Methods

The study was conducted in the *Acacia tortilis* (tree) + *Cenchrus ciliaris* (grass) based silvopastoral systems at Central Research Farm of Indian Grassland and Fodder Research Institute, Jhansi (25^{o} 25'N and 78^{o} 35'E and 275 msl) for two years. The site had sandy clay loam soil. The mean rainfall was 915.55 mm and average mean maximum and minimum temperatures were 32.0^{o}C and 17.2^{o}C. *Acacia tortilis* was planted at 4 x 4 m spacing in 1982 while *Cenchrus ciliaris* was re-established in 1995 at the spacing of 50 x 50 cm. The plot size was 20 x 24 m arranged randomly in three replications along with control plots (without trees). The plant materials were managed as per recommended agronomical practices. Tree growth data were recorded at six monthly intervals.

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Height was measured by the calibrated meter rod. Collar diameter (CD) was measured at the 20 cm of stem base and diameter at breast height (dbh) at 137 cm height above ground level with the help of a tree caliper. Growth observation on plant height, leaf area and biomass production of *C. ciliaris* was recorded in rainy season (September) and post rainy season (December) at 50% flowering stage of crop growth. The leaf area of fresh leaf was measured by an automatic portable leaf area meter (Model CI-3000, LICOR, USA) before weighing. The plant samples were dried in an electric oven at 80°C for 48 hr to record the dry matter yield. The specific leaf weight (SLW) was observed as dry matter accumulation in per unit leaf area.

PAR and canopy temperature (CT) in open and under tree canopies were measured by using the Line Quantum Sensor in Radiometer/ Quantum / Photometer (LICOR, Model 188) and Infra-red Thermometer (AG-42) respectively. The soil temperature and moisture were measured by placing soil thermometer and soil moisture block at different soil depths. Rate of photosynthesis, transpiration, stomatal conductance and inter cellular CO_2 concentration of leaf of *C. ciliaris* was measured by using portable photosynthesis system (Model LI-6200, LICOR, USA) during noon hours on a clear sky day. Photosynthetic pigment in fresh leaves was determined by the method of Duxbury and Yantsch (1956) and the fraction of chlorophyll was calculated by the equation given in AOAC (1970) and expressed in mg g^{-1} of the fresh weight. The N, P, K, Ca and Mg were estimated in the oven dried samples of *C. ciliaris* during the second year of experimentation. Total nitrogen was estimated by Microkjeldal method (AOAC, 1960). Phosphorus was estimated by using the method of Kitson and Mellon (1944). Potassium and calcium were analyzed by Digital Flame Photometer. Magnesium content in leaves was estimated by thizole yellow described by Johnson and Ulrich (1959) and modified by Yadava *et al.* (1969). The crude protein was calculated from the estimated nitrogen. Sugar and starch contents in dry samples of leaves were estimated by Anthrone method (Morris, 1948).

The soil samples were taken from three depths *viz;* 0-15, 15-30 and 30-45 cm for soil moisture estimation. The soil of two depths (0-15 and 15-30 cm) in open grown grasses and under the system of *A. tortilis* + *C. ciliaris* were analyzed for pH, moisture, organic carbon and available N, P, K by using standard methods. Organic carbon was estimated by Walkley and Black method (Jackson, 1958).

Results and Discussion

Growth performance of trees: The tree height, collar diameter and dbh of *Acacia tortilis* were 9 m, 26.30 cm and 24.20 cm respectively after 17 yr of its growth in semi arid tropics. The height increment was only 0.2 m and collar diameter and dbh growth were 0.5 and 1.2 cm respectively in two year of its growth indicating that this tree species has attained a platue in height increment and therefore, the further rate of extension growth is extremely slow. At the time of starting observations the canopy spread was 8.28 and 7.34 m in North – South and East – West direction. At the end of two years of growth, the canopy growth was 9.18 and 8.15 m in North – South and East – West direction respectively. The observations revealed that in *Acacia tortilis* the canopy growth was only 0.9 m in North-South and 1.17 m in East- West direction after 2 yr of growth. The maximum active growth with respect to height, CD and dbh was observed between March to September.

Micro-climatic changes: On average of all the seasons of two years, full grown canopies of *A. tortilis* transmitted 55% of total photosynthetically active radiation (PAR). The PAR transmission increased gradually from January and reached maximum in May-June because of leaf senescence. The reduction in the availability of PAR under tree canopies led to decreased under canopy temperature. The under canopy temperature of *A. tortilis* was lower to air temperature. The canopy temperature during the full canopy growth was 33.5°C as recorded in the month of Sep-Oct. On average of two years data the canopy-air temperature difference was -1.7°C (Table 1). The temperature under tree canopies was dependent of radiation availability (r=0.6731). In general relative humidity was higher under silvopasture system as compared to the open field. Soil temperature decreased at different depths under *A. tortilis* + *C. ciliaris* system as compared to open. Similarly, Hazra and Tripathi (1986) observed lower temperature under canopies of *Albezia lebbeck, Acacia nilotica* and *Leucaena leucocephala*. It is evident from the Fig. 1 that variation in soil moisture was quite high at different depths during different months under tree canopies as compared to open. During rainy months the moisture availability was quite high as compared to the post rainy months (December to May). In the post rainy and summer season the soil moisture content was relatively high at higher depth under tree canopies as compared to the open field. The maximum soil moisture was recorded at different depth in the month of August which may be due to maximum rainfall and rainy days in this month. The decrease in under canopy temperature and increase in relative humidity with lower availability of light under tree canopies during day time caused reduction in evapo-transpiration through which the soil moisture increases. This available soil moisture helped in sustaining the growth and biomass production in the post rainy season.

Morphological characters of grasses: The plant height of *C. ciliaris* increases under the shading of *A. tortilis* canopies as compared to the open grown grasses. Average plant height of *C. ciliaris* was 146.08 cm under *A. tortilis* trees in silvopasture system whereas it was 138.12 cm in open (Table 1). Bhatt *et al.* (2002) have also reported similar trend in height increment under shade in some grass species. Shading of the tree canopies caused reduction in tiller and leaves production as also reported by Dodd *et al.* (2005) and Peri *et al.* (2007). The decrease in number of leaves and tiller per tussock caused reduction in leaf area index under tree canopies. The specific leaf weight (SLW), which indicates the accumulation of dry matter per unit leaf area, also decreased under tree canopy as compared to grasses grown in open field without trees. In general this grass species accumulated 6 to 7 kg dry

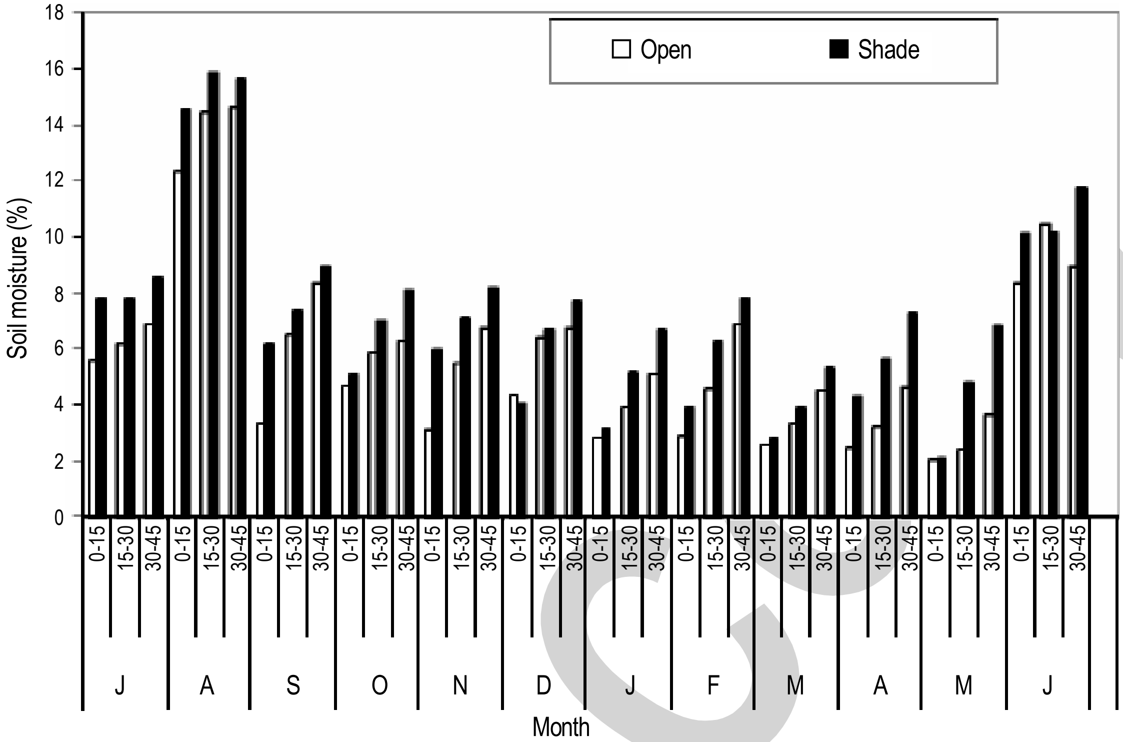

Fig. 1: Variation in soil moisture content at different depths in open and under *A. tortilis+C.ciliaris* (shade) based silvopasture system

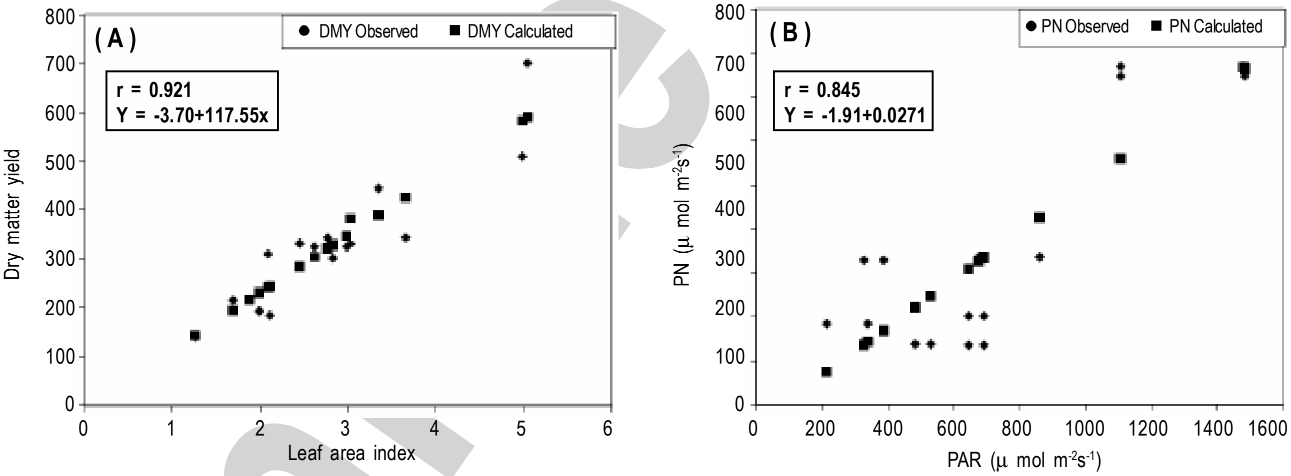

Fig. 2: Linear relationship between dry matter yield (DMY) vs leaf area index (LAI) (A) and photosynthesis (PN) vs Photosynthetically active radiation (PAR) (B)

matter m^{-2} leaf area. The total biomass production in term of fresh and dry weight also decreased under the tree canopies (Table 1). On average of two years *C. ciliaris* had produced 17.76 t ha^{-1} green biomass in open field and 12.78 t ha^{-1} under tree canopies of *A. tortilis*. The reduction in forage yield was 27% under tree canopies over the open grown grasses. On average *C. ciliaris* produce 3.72 t ha^{-1} dry matter yield under shade of tree canopies. Reduction in biomass production was about 38% under the tree canopies of *A. tortilis,* where the infiltered PAR was 55%. The dry matter yield was significantly correlated (r=0.979) with available PAR exhibiting that for the optimum production of this grass species under tree canopies more than 55% of total PAR is required. Reduction in dry matter production in shade grown plants has also been reported earlier (Singh *et al*., 1988; Douglas *et al.,* 2001). The biomass production is intimately associated with the influence of micro environmental parameters as evident from the positive and significant correlation coefficient (Table 2). The highly significant correlation coefficient (r = 0.921) of dry matter yield with leaf area index indicate the interdependence of these characters (Fig. 2).

Table - 1: Micro environmental changes, growth and physiological characters of *C. ciliaris* in open and under canopy of *A. tortilis* in the silvopasture system (Average of two years data) (Data in parenthesis indicates percentage reduction and gain)

Parameters / Characters		Open	Under tree canopy	CD at 5%
Micro environmental parameters				
Photosynthetically active radiation (PAR) (μmole m^{-2} s^{-1})		1513	835 (-45)	23.37
Canopy temperature (°C)		31.6	29.8 (-5.7)	0.01
Canopy temperature – Air temperature (°C)		-	-1.75	-
RH (%)		63.5	67.5 (+6.3)	0.62
Soil temperature (°C)	0 – 15 cm soil depth	26.43	25.53 (-3.40)	-
	15 – 30	25.90	25.26 (-2.47)	-
	30 – 45	25.86	25.23 (-2.43)	-
Growth characters				
Plant height (cm)		138.12	146.08 (+5.45)	2.36
Tiller production (Nos/tussock)		40.71	37.4 (-8.13)	0.56
Leaves production (Nos/tiller)		12.90	11.0 (-14.73)	NS
Leaf area index		3.15	2.90 (-7.94)	NS
Specific leaf weight (mg cm^{-2})		6.85	6.35 (-7.29)	0.12
Fresh biomass yield (t ha^{-1})		17.67	12.78 (-27.67)	1.06
Dry biomass production (t ha^{-1})		6.02	3.72 (-38.20)	0.61
Physiological characters				
Leaf temperature (°C)		33.06	30.60 (-7.44)	0.21
Photosynthetic rate (μmole m-^{2} s^{-1})		38.78	18.54 (-52.20)	1.43
Stomatal conductance (cm s^{-1})		1.15	0.75 (-34.80)	0.13
Transpiration rate (mmole m^{-2} s^{-1})		8.40	6.76 (-19.52)	1.51
Intercellular CO_2 concentration (ppm)		155	231 (+49.03)	32.33
Carboxylation efficiency (PN/CINT)		0.27	0.08 (-70.37)	0.02
Photosynthetic water use efficiency(PN/TR)		4.61	2.74 (-40.56)	0.91
Chl a		2.58	2.87 (+11.24)	0.17
Chl b		0.93	1.18 (+26.88)	0.13
Chl a+b		3.51	4.05 (+16.24)	0.24
Chl a:b		2.77	2.43 (-12.27)	NS
Quality attributes				
Crude protein (%)	Leaves	7.99	10.93 (+36.79)	0.13
	Stem	5.17	6.51 (+25.92)	0.06
Sugar (%)	Leaves	2.17	2.45 (+12.90)	0.11
	Stem	2.35	2.65 (+12.76)	0.13
Starch (%)	Leaves	7.02	8.06 (+14.81)	0.46
	Stem	7.12	8.25 (+15.87)	0.39
Nitrogen (%)	Leaves	1.27	1.75 (+37.80)	0.02
	Stem	0.84	1.04 (+23.81)	NS
Phosphorus (%)	Leaves	0.62	0.61 (-1.61)	0.02
	Stem	0.39	0.36 (-7.69)	0.01
Potassium (%)	Leaves	1.60	2.19 (+36.87)	0.04
	Stem	1.02	1.30 (+27.45)	0.06
Calcium (%)	Leaves	4.13	5.01 (+21.31)	0.04
	Stem	2.26	2.31 (+2.21)	0.07
Magnesium (%)	Leaves	3.45	2.93 (-15.07)	0.15
	Stem	3.44	3.46 (-0.57)	0.37

Assimilatory functions: As expected the leaf temperature of *C. ciliaris* was lower under tree canopies as compared to grass grown in open field conditions (Table 1). It might be due to the variation in availability of radiation and rate of transpiration under the tree canopies. As reported by various workers the leaf temperature is species dependent (Purohit *et al*., 1983; Bhatt *et al*., 1991). Rate of photosynthesis decreased significantly under the tree canopies due to lower availability of PAR. Maximum rate of photosynthesis (PN) was 38.78 μmole m^{-2} s^{-1} in open field which reduced to half under tree canopies (18.54 μmole m^{-2} s^{-1}) (Table 1). Rate of photosynthesis linearly correlated with the available PAR (r = 0.84) (Fig. 2). Reduction in photosynthetic rate under the shading of tree canopies might be due to lower stomatal conductance (CS), which also declined with decreasing light intensity. The photosynthetic rate is strongly associated with stomatal conductance as evidenced by positive and significant correlation (r = 0.95) between these two parameter. In

Table - 2: Correlation coefficient among various growth, physiological and microenvironmental parameters

Parameters	Height	LAI	GMY	DMY	PAR	AT	RH	ST	SM	PN	CS	TR
Height	1.0000											
LAI	0.8362	1.0000										
GMY	0.8716	0.9330	1.0000									
DMY	0.7313	0.9187	0.9377	1.0000								
PAR	0.0023	0.1524	0.0873	0.0979	1.0000							
AT	0.6158	0.5508	0.5587	0.4021	0.6731	1.0000						
RH	0.7115	0.5588	0.5584	0.3446	0.4531	0.9473	1.0000					
ST	0.6607	0.5776	0.5993	0.4079	0.5939	0.9721	0.9639	1.0000				
SM	0.6452	0.4999	0.4410	0.2533	0.2962	0.3566	0.5926	0.4249	1.0000			
PN	0.4256	0.4952	0.5118	0.4467	0.8388	0.8966	0.7256	0.8377	0.0299	1.0000		
CS	0.5463	0.5898	0.5761	0.4810	0.7389	0.9583	0.8499	0.8937	0.2575	0.9451	1.0000	
TR	0.5181	0.5997	0.5594	0.4788	0.7703	0.9374	0.8234	0.8715	0.2741	0.9305	0.9852	1.0000

Critical value (1-TAIL, 0.05 = + or - 0.42706), Critical value (2-TAIL, 0.05 = + or - 0.49580), LAI = Leaf area index, GMY = Green matter yield, DMY =Dry matter yield, PAR=Photosynthetically active radiation, AT=Air temperature, RH=Relative humidity, ST=Soil temperature,SM=Soil moisture, PN=Rate of photosynthesis CS=Stomatal conductance, TR=RAte of transpiration

Table - 3: Changes in soil health under *A. tortilis+C.ciliaris* based silvopasture system

Soil parameters	Soil depth	Open		Under canopy		CD at 5%		
		Initial year	After two years	Initial year	After two years	System	Depth	S x D
Soil pH	0-15	5.93	5.33	6.11	5.91	NS	0.11	NS
	15-30	6.47	5.73	6.3	6.09			
	Mean	6.20	5.53	6.20	6.00			
OC (%)	0-15	0.426	0.505	0.690	0.882	0.05	0.06	0.08
	15-30	0.406	0.440	0.499	0.640			
	Mean	0.42	0.47	0.59	0.76			
N (kg ha^{-1})	0-15	185.3	196.9	228.5	259.2	22.51	NS	NS
	15-30	196.4	215.1	225.9	235.9			
	Mean	190.8	206.0	227.2	247.5			
P (kg ha^{-1})	0-15	6.96	7.90	7.82	7.71	0.24	0.29	0.41
	15-30	7.21	8.90	7.31	7.83			
	Mean	7.08	8.40	7.56	7.72			
K (kg ha^{-1})	0-15	102.0	123.2	108.0	134.4	NS	NS	NS
	15-30	106.0	134.4	106.0	126.4			
	Mean	104.0	128.8	107.0	130.4			

contrast to the rate of photosynthesis intercellular CO_2 concentration (CINT) increased significantly under shade of the tree canopies causing lower fixation of CO_2. Similar to the rate of photosynthesis the carboxylation efficiency (PN/CINT), (Farquhar and Sharkey, 1982) decreased under the shade of tree canopies. The reduction in transpiration (TR) under the shading environment of trees was also caused by lower availability of PAR and stomatal conductance as also supported by strong positive correlation with these parameters. The photosynthetic water use efficiency (PN/TR) reduced under the shade of tree canopies. Rate of photosynthesis, stomatal conductance, transpiration and dry matter yield are positive and significantly associated with the available PAR as evident from the correlation coefficient among these parameters (Table 2). The highly significant correlation of these parameters with PAR is suggestive of the fact that these physiological processes are mainly influenced by this environmental parameter.

Photosynthetic pigment: The accumulation of photosynthetic pigments (chl a and b) in *C. ciliaris* was higher under tree canopies than the open field (Table 1). The increase in total chlorophyll accumulation under shade might be due to more accountability of chlorophyll b, which indicates shade adaptation ability of this grass species. Higher content of chl b in shade plants was also reported by Good child *et al*. (1972), Bhatt and Sinha (1990) and Singh (1994).

Quality characters: The quality of *C. ciliaris* improved under the shading of tree canopies as indicated by higher accumulation of protein, carbohydrates and nutrients. Crude protein content in leaf and stem was higher under tree canopies (Table 1). The protein accumulation was more in leaves than the protein content in stem. The crude protein is directly related with the available nitrogen content in the leaves and stem and it is assumed that under high shading environment the inorganic nitrogen in the form of nitrate was more, which might be due to slow process of nitrogen assimilation. Accumulation of sugar and starch in leaves and stem was higher under the shading of tree canopies as compared to open grown grasses indicating the slow translocation of carbohydrates to other plant parts. Nitrogen in leaves and stem was higher under the shade of tree canopies. In contrast to nitrogen the phosphorus in leaves and stem of grass species decreased under the shade of tree canopies exhibiting that lower light intensity has the major influence on phosphorus accumulation. Similar to the nitrogen, potassium in leaves and stem was higher under the shading environment of tree canopies. *C. ciliaris* has also maintained higher quantity of calcium in stem under the tree canopies indicating its shade tolerance. Similar findings were also reported by Bhatt *et al.* (2002) in different grasses and legumes under shading environment. The accumulation of magnesium in leaves decreased under the shade environment whereas in stem it was at per with open grown grass.

Changes in soil health: The pH of the soil under silvopasture system of *A. tortilis* + *C. ciliaris* was slightly higher than the sole pasture of *C. ciliaris.* Significant changes in organic carbon content were observed under the tree canopies of *A. tortilis* (Table 3). Higher organic carbon was observed at the top layer (0-15 cm) soil depth in the pure grasses as well as in the silvopastoral systems. The increase in organic carbon under the silvopasture system may be because of more litter decomposition and available root biomass of trees and grasses. Maximum nutrients were estimated at the top layer of the soil than at different depths (Table 3). The available nitrogen, phosphorus and potassium in soil were higher in the silvopasture system as compared to the pure grass stand of *C. ciliaris.* The phosphorus availability in the pure grass stand of *C. ciliaris* and *A. tortilis* + *C. ciliaris* system increased with increasing soil depth. At the top layer (0-15 cm) the available potassium was higher under the *A. tortilis* + *C. ciliaris* system. On average there was improvement in potassium availability at the end of growth season in the pure grass stand as well as under silvopasture system. The higher level of nutrients under *A. tortilis* + *C. ciliaris* based silvopasture systems over the years may be due to decay of litter, root biomass and other organic carbon matter. Many workers have also reported the more availability of nutrients under tree cover (Sanchez, 1987; Nair, 1989; Udawatta *et al.,* 2008). The increase in organic carbon under the silvopasture systems indicates the improvement in soil health, which in turn results in higher system productivity and sustainability. On the basis of the results obtained in the present study it can be concluded that the *A. tortilis* + *C. ciliaris* silvopasture system is the sustainable forage production system for the semi arid tropics of India.

Acknowledgments

The authors are thankful to the Director and Head of Division, IGFRI, Jhansi for providing facilities.

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