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Comparative performance of some agri-silvi-horti systems with drip irrigation under arid regions

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ABSTRACT

The combinations of different tree species namely guava (*Psidium guajava*) + *shisham* (*Dalberiga sissoo*), guava (*Psidium guajava*) + *khejri* (*Prosopis cineraria*), *aonla* (*Embilica officinalis*) + *shisham* and *aonla* + *khejri* were planted during Oct. 2000 at a spacing of 6 m × 6 m. After establishment of trees from July 2001 the crop sequences, *viz.*, ridgegourd (*Luffa acutangula*)- tomato (*Lycopersicon esculentum*), moongbean (*Vigna radiata*) - fallow and clusterbean (*Cyamopsis tetragonoloba*)- fallow were raised in the interspaces of the trees. Ridgegourd and tomato were raised with drip irrigation (100, 70 and 40% ETc), while moongbean and clusterbean were raised as rainfed crops. In general, maximum plant growth (height and diameter) was recorded under 100% level of irrigation for all the tree species. The tree species showed significant variation in growth. Irrigation treatments varied significantly only for diameter. The yield of intercrops was significantly affected by different irrigation levels and was highest at 100% irrigation level but it was not affected by different tree species. The highest yield of 385, 925, 5300 kg/ha of moongbean, clusterbean and ridgegourd were recorded under guava + *khejri* at 100% ETc irrigation level. During *rabi* season (winter; November-March) maximum yield of tomato (46,220 kg/ha) was observed under 100% ETc. Water use efficiency for trees ranged from 1.19 to 11.0 g/l. Maximum WUE was observed in ridgegourd at all the irrigation levels under different systems.

Key words*:* Drip irrigation, agri-silvi-horti system, crop evapotranspiration, water use efficiency.

INTRODUCTION

The Indian hot arid zone covers about 10% of the country's geographical area. The arid tropics generally have relatively hostile environmental conditions, such as low and erratic rainfall, intense solar radiation and high wind velocity. The soils are immature, structure less, coarse textured with low water holding capacity and poor nutrient status. The moisture deficit conditions dominate for a long time throughout the year, which acts as the major limiting factor for establishment and growth of woody plant species. Water is a basic input for agriculture and that may be considered to be the most crucial resource. Most of the cropping systems operating in the limited irrigated area of arid ecosystems have very high water requirement and are highly unsustainable. Hence, location-specific models have to be developed involving fruit crops, multipurpose tree species and arable crops in an agri-silvi-horti production system for increasing water use efficiency (WUE), productivity, profitability and sustainability of the system.

The prevailing soil and climate conditions of the arid ecosystem are not congenial for the surface irrigation system. Method of irrigation not only optimizes the WUE but also plays a significant role in regulation of the harvest depending upon the time. The irrigation system, drip system is more appropriate for tree crops in arid ecosystem. According to Buck and Nakayama (4) drip irrigation has the greatest potential where: (i) water is expensive or scarce; (ii) soils are sandy, rocky or difficult to level; and (iii) high value crops are produced. Drip irrigation which discharges the water in root zone of the plant resulting in efficient utilization of water has already found favour for its commercial exploitation in this region. Since, drip irrigation economizes the water use, area under irrigation can be doubled with same quantity of water. Therefore, the present studies were conducted to work out the water requirement of a location specific agri-silvi-horti system with drip irrigation.

MATERIALS AND METHODS

The field experiment was conducted at CCS Haryana Agricultural University Regional Research Station, Bawal, located in the low rainfall zone of the southern Haryana (28.1°N, 76.5°E and 266 m above mean sea level). In general, May-June are the hottest (0-15°C), while December-January are the coldest (21-47°C) months of the year. The site is characterized by inadequate precipitation (300-500 mm) during monsoon (July-September) and is also quite erratic. The number of rainy days in a year varies between 15 to 25. During summer, the maximum temperature

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reaches as high as 47°C. Whereas, during peak winter months of December and January, the average minimum temperature is recorded around 4-5°C, which at times, reaches below 0°C. Between October and March, weather remains almost dry except occasional light showers. Thereafter, it is quite dry till June. High temperature along with peak evapotranspiration rate of 5.3 mm/day is observed from July to October and 2.7 mm/day from November to February. The maximum evapotranspiration rate of 14 mm/day is recorded in the month of June.

The combinations of different tree species namely *shisham* (*Dalbergia sissoo*) + *aonla* (*Emblica officinalis*), *shisham* + guava (*Psidium guajava*), *khejri* (*Prosopis cineraria*) + *aonla* and *khejri* + guava were planted during October, 2000 at a spacing of 6 m x 6 m. Young budded plants of guava, *aonla* and seedlings of *D. sissoo* and *P. cineraria* raised in polythene bags for eight months were used as planting material. The plants were raised following cultural practices recommended for the region. Plants were protected against termite by applying endosulfan/chlorpyriphos (2 ml/l) with irrigation water. After establishment of trees the crop sequences, *viz*., ridgegourd (*Luffa acutangula*), tomato (*Lycopersicon esculentum*), moongbean (*Vigna radiata*) - fallow and clusterbean (*Cyamopsis tetragonoloba*) - fallow were raised in the interspaces of the trees. Ridgegourd and tomato were raised with drip irrigation, while moongbean and clusterbean were raised as rainfed. The details of variety, seed rate, spacing, fertilizer and cultural practices adopted for various crops are presented (Table 1).

A single lateral drip line was placed on the soil surface in each tree row. Each tree was provided with two drippers (emitters) having discharge rate of 4.01/h. During the first 16 months after planting, all trees were irrigated equally to ensure the uniformity of plant growth. The trees were subjected to three drip irrigation treatments, *viz*., T_1 (100% ETc), T_2 (70% ETc) and T_3 (40% ETc) with three replications per treatment distributed in split plot design. The water applied in T_1 was considered sufficient to fully satisfy the needs of the crop (100% ETc). Irrigation treatments were based on crop evapotranspiration (ETc, mm), considering rainfall and was derived from class A Pan Evaporation (Doorenbos and Purit, 6) placed in the proximity of a standard meteorological station adjacent to the experimental field. The total amount of irrigation (litre/plant) applied in T_1 was calculated as per Dorrenbos and Pruit (6). The trees were irrigated on every alternate day. The drip irrigation system was operated during evening hours to avoid evaporation losses. The growth performance was recorded in terms of height and collar diameter. In each treatment, observations were recorded on nine plants after excluding the border plants. Biomass was estimated from girth by the formula (Shorrock *et al*., 15). The yield of different crops was also recorded. Water Use Efficiency (WUE) was calculated by dividing the biomass increment due to irrigation with the quantity of water applied. The WUE was calculated on fresh weight basis. Moisture distribution pattern was measured by installing two access tubes, 25 and 50 cm away from the dripper at one site (tree) and replicated thrice in each treatment. The moisture percentage data was recorded with the help of soil moisture meter (Diviner 2000, Australia). Distance of access tube was kept near to the drippers during the initial two years of the establishment, there after it will be increased according to the age of the trees from two to four.

RESULTS AND DISCUSSION

Different tree species varied significantly in terms of growth. *D. sissoo* showed significantly higher growth (plant height and diameter) over rest of the tree species, irrespective of irrigation levels. Initially the drip irrigation treatments influenced the growth of trees but at the age of 24 months the plant height differences were non-significant, however the differences for diameter were significant. All the tree species showed better growth under 100% ETc replenishment of water except *D. sissoo* in which maximum growth was observed with 70% ETc level of irrigation at both stages of observation, *i.e*., 12 and 24 months of age (Table 2).

Table 1. Management practices followed for raising crops.

Crop	Variety	Seed rate (kg/ha)	Spacing (cm)	Fertilizer (kg/ha)		
				N	P	K
Cluster bean	HG-365	15.0	30 × 15	20	40	20
Ridge gourd	Pusa Nasdar	3.5	200 × 100	25	30	10
Tomato	Naveen	0.5	100 × 50	120	60	40
Moong bean	Muskan	15.0	30 × 10	20	40	10

Table 2. Plant height (cm) and diameter (cm) of different tree species under drip irrigation system after 12 and 24 months of planting.

Tree species	Irrigation level (ETc)					
	100%		70%		40%	
	Height	Dia	Height	Dia	Height	Dia
12 month						
Dalbergia sissoo	240	4.44	263	4.18	238	2.46
Emblica officinalis	146	2.55	147	2.56	126	1.46
Prosopis cineraria	135	1.59	109	1.33	108	1.18
Psidium guajava	121	2.62	109	2.29	095	1.08
24 month						
Dalbergia sissoo	430.0	9.2	441.0	9.8	413.3	8.8
Emblica officinalis	262.0	4.8	260.6	5.1	253.7	4.4
Prosopis cineraria	175.0	4.2	172.3	3.9	189.7	3.5
Psidium guajava	187.7	4.4	180.7	4.3	164.0	3.9

CD at 5%	Height		Diameter	
	12	24	12	24
Tree	0.84	14.3	0.23	0.46
Irrigation	0.13	NS	0.29	0.35
Interaction	NS	NS	NS	NS

The plant height and diameter showed significant differences between irrigation treatments in 1st year of experiment. During 2nd year, plant height showed non-significant differences between the irrigation treatments for all the tree species. In general, the amount of water supplied by different irrigation treatments affected the vegetative parameters and no conclusion could be drawn. The irrigation treatments influenced the growth in terms of stem diameter. It may be due to the fact that the moisture is a critical factor responsible for growth of woody plant species. Increase in plant height, stem girth, relative leaf water content and fruit yield with the increase in evaporation-replenishment rates have also been observed by Srinivas (16) in papaya. Increased frequency of irrigation resulted in significant increase of diameter in poplar trees (Kaushik and Singh, 11). Many authors have described the positive effect of an increase in water supply on different fruit crop species, *viz*., Assam lemon (Barua *et al*., 2), pomegranate (Chopade and Gorantiwar, 5). However, our results do not permit us to infer any significant effect of the amount of water supplied on growth of tree species nor did Franco *et al*. (9) observed differences from 60 to 100% of the ETc in almond.

The tree species varied significantly for plant height and diameter at both the stages of observations and *D. sissoo* showed the maximum growth followed by *E. officinalis* irrespective of irrigation treatments. Variation in growth might be due to differences in genetic make up of different tree species, which is exhibited in plants particularly when raised from seeds. The maximum growth in *D. sissoo* in terms of height and diameter may be due to its inherent fast growing habit. The results are in agreement with our earlier findings (Kaushik *et al*., 12).

Irrigation treatments influenced the yield of tomato and ridgegourd significantly. Maximum tomato yield (46,250 kg/ha) was obtained when the plants were irrigated on the basis of 100% ETc. The yield of moongbean and clusterbean was non-significant under all the irrigation levels (irrigation applied only to trees) as these crops were grown as rainfed. The yields of different field crops grown in the interspaces of different tree species were at par, indicating that the silvi-horti system (different tree combinations) of 2-year age did not affect the yield of inter crops (Table 3). The yield of arable crops was similar under different tree combinations. This might be due to less crown area and low interception of light by trees in the initial years. Earlier, Evans *et al*. (7) have argued that although growth of plant species is controlled by various environmental factors, but among these light is most important. These results are in agreement with the findings of Kaushik *et al*. (12).

Positive effect of an increase in water supply on crop production of tomato and ridgegourd was observed. Maximum yields of both these crops were recorded with maximum supply of water, *i.e*., 100% ETc. In general, the amount of water applied by the different irrigation treatments affected the yield of

Table 3. Y.ield (kg/ha) of intercrops (*kharif*) as affected by different trees and irrigation scheduling under drip irrigation system (av. of 2 years).

Intercrop/Tree	Irrigation level (ETc)											
	100%				70%				40%			
	Moong bean	Cluster bean	Ridge gourd	Tomato	Moong bean	Cluster bean	Ridge gourd	Tomato	Moong bean	Cluster bean	Ridge gourd	Tomato
Shisham + guava	361	880	5262	46,140	350	915	5064	43,600	335	862	4765	34,570
Shisham + *aonla*	356	900	5230	45,970	360	850	4930	43,940	310	908	4680	34,170
Khejri + guava	385	925	5300	46,070	330	850	5000	43,400	370	899	4600	33,540
Khejri + *aonla*	300	897	5183	46,220	350	890	5092	43,800	335	885	4663	34,400

CD at 5%	Moong bean	Cluster bean	Ridge gourd
Tree	NS	NS	NS
Irrigation	NS	NS	215
Tree × Irrigation	NS	NS	NS

vegetable crops. A number of workers have observed a positive effect of amount of water supply on yield of different vegetable crops (Andrade *et al*., 1; May, 13).

Consumptive use of water by different tree species increased with the increase in level of irrigation. Maximum water was used by *D. sissoo* and minimum by *P. cineraria* (Fig. 1). This may be due to increase in water status, decrease in stomatal resistance and greater vapour pressure gradient between canopy and the air above tree level under wet conditions. Consumptive use of water by different tree species increased progressively with the increase in level of irrigation (Fig. 1). Consumptive use of water was highest at 100% ETc and the lowest at 40% ETc in all the tree species and tomato crop. This may be due to increase in water stress, decrease in stomatal resistance and greater vapour pressure gradient between canopy air and the air above the tree level under wet conditions than under moisture stress treatment. Bhuva *et al*. (3) indicated the increase in ET with increase in level of irrigation.

Water use efficiency for different tree species varied from 1.19 to 11.0 g/l. Maximum WUE was recorded under 40% ETc treatment of irrigation for all the tree species and tomato crop (Fig. 2; Table 4). In general, forest tree species showed more WUE as compared to fruit tree species. This suggests that the water use efficiency decreased with the increase in levels of irrigation. This may be due to the fact that biomass produced by the trees did not increase in proportionate to total water used by the tree species. Further, Fisher and Turner (8) also suggested that plant characters such as leaf morphology, leaf anatomy, stomatal apertures and plant ontogeny, in addition to the environment, can significantly affect the WUE. The WUE was maximum with tomato followed by dolichos

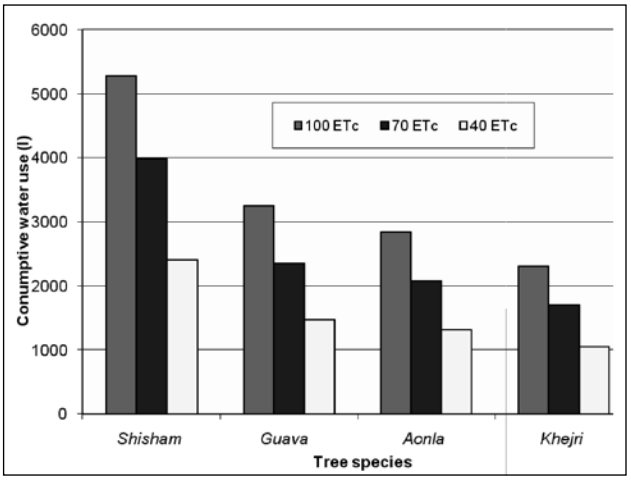

Fig. 1. Consumptive water use of tree species under different irrigation levels.

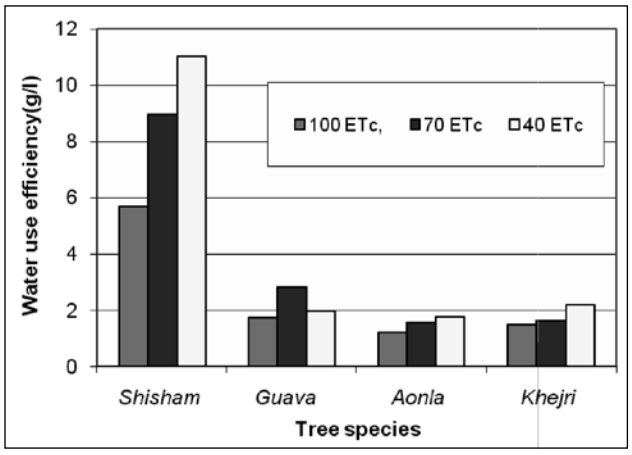

Fig. 2. Water use efficiency of tree species under different irrigation levels.

Table 4. Water use efficiency (g/l) of tomato and ridgegourd under different tree species with drip irrigation system.

Tree species	Water use efficiency					
	Tomato			Ridge gourd		
	100%	70%	40%	100%	70%	40%
Shisham + *aonla*	4.29	5.77	8.00	7.50	10.10	16.70
Shisham + guava	4.15	5.68	7.92	6.60	8.80	14.50
Khejri + guava	5.48	7.30	9.93	11.90	15.80	26.10
Khejri + *aonla*	5.75	7.27	10.86	12.60	17.70	28.80

bean, while chilli recorded the lowest WUE (Hedge and Srinivas, 10). These findings are in conformity with those of Bhuava *et al.* (3), and Nade (14).

Ridgegourd-tomato sequence was most remunerative with all the tree species followed by clusterbean - fallow sequence. However, negative returns of Rs. 1,300/- were obtained under 70% irrigation level with *D. sissoo* and *P. guajava* tree combination for clusterbean-fallow rotation. Negative returns from moongbean-fallow rotation may be due to drought as the crop was raised rainfed crop (Table 5). The economic viability of a system is the most important consideration for adoption of any technology at the farmer's field. Among various crops ridgegourd-tomato rotation under all the tree species gave maximum net returns. This might be due to higher yield of these crops. Clusterbean-fallow followed the ridgegourd-tomato rotation in terms of net returns.

Table 5. Economics (Rs./ha) of the agri-sivli-horti system developed under drip irrigation after 2-years of plantation.

Tree species	Irrigation level (ETc)								
	Cucurbit-tomato			Cluster bean-Fallow			Moong bean-Fallow		
	100%	70%	40%	100%	70%	40%	100%	70%	40%
Shisham + *aonla*	162955	152193	116113	1260	1100	-20	-5500	-5270	-5600
Shisham + guava	164393	153413	118233	-500	-1300	300	-6430	-6750	-5600
Khejri + guava	164833	150433	135837	1100	300	1100	-5230	-5990	-6470
Khejri + *aonla*	164873	154833	119033	300	-20	-340	-6670	-6470	-5990

Moong bean-fallow, gave negative returns. This might be due to less yield of moong bean because of the drought. Economic evaluation of different agri-silvi-horti system during the course of investigation showed that the ridge gourd - tomato associated with all the tree species fetched highest returns. These results are in agreement with the findings of Suresh and Rao (17), and Kaushik *et al*. (12)

The present study proves that the different tree species did not affect the yields of arable crops during the establishment period. *D. sissoo* and *P. cineraria* can be established with 40% ETc of water replenishment. The irrigation levels influenced the yield of tomato and ridgegourd. The most economic crop sequence was ridgegourd-tomato. Further studies are in progress to work out the water requirement and irrigation scheduling of different agri-silvi-horti systems.

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