

Agri-horti-silvi system

for production stability in arid zone

N. D. Yadava¹, M. L. Soni², V. S. Rathore³ and N. S. Nathawat⁴

Regional Research Station, Central Arid Zone Research Institute, Bikaner (Rajasthan) 334 004

Indian arid zone has many constraints and limitations for agriculture. Crop season water scarcity, poor and erratic rainfall, very light coarse sandy soil with poor water-holding and nutrient content, high temperature (49 °C) with high wind velocity during summer causes rapid evaporation and infiltration rate. Woody perennial with intercropping of annual crops is only option for production security and sustainability in this region and agri-horti-silvi system proved one of the best systems of cropping in this region.

Key words: Agri-horti-silvi system, Arid zone, Drip irrigation, Sustainable production



Fig. 1. Citrus + mustard in agri-horti system

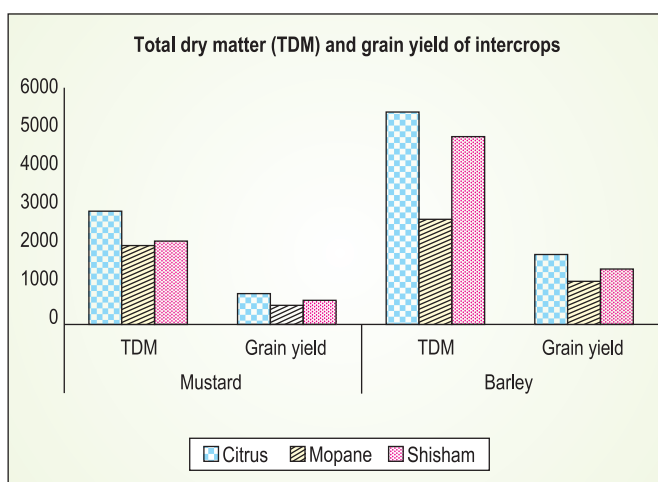


Fig. 2. Yield of mustard and barley with different trees.

THE hot arid region of India, covering an area of 31.70 million ha, is mostly spread in Rajasthan, Gujarat, Punjab, Haryana and together constitute the Great Indian desert, better known as the Thar desert. Production system in this region is confronted by several edapho-physical constraints, such as low and erratic rainfall, extreme temperature variations as high as 49°C during summer and less than 0°C during winter, wind erosion, low soil fertility etc. Due the harsh climatic conditions of the region, arable crop production is risky and

poses a great threat to agriculture. Under such situation, woody perennial-based production system is considered effective strategy for improving productivity, employment opportunities, economic and nutritional security.

The integration of suitable under and ground storey crops with the hardy fruit/timber/energy trees was found remunerative, providing fruit, food, fuel and fodder to the farmers. Neither the concept nor the practice of agri-horti-silvi is new, the word agri-silvi-horti has transformed this ancient practice into a fruitful science

and scientific methods to yield significant returns. For Millennia, farmers of arid region nurtured trees on their farms and in the farming landscape for many benefits. The trees are generally present in an unorganized manner on the traditional agricultural systems, yet farmers retain the trees along with agricultural crops for their daily domestic demand. Such multifarious fruits and forest trees when present with agricultural crops in system approach form agri-horti-silvi system. The hardy perennial fruit trees, such as *ber* (*Ziziphus mauritiana*), *bael*

Table 1. Recommended agri-horti crops component for Indian arid regions

Growing conditions	Horticultural component			Crop component
	High storey	Medium storey	Ground storey	
Rainfed (150–300 mm)	Bordi and Indian mesquite	<i>Jhar ber</i>	Cucurbits and clusterbean	Clusterbean, moth bean, pearl millet and sesame
Rainfed (300–500 mm)	Indian jujube and Indian mesquite	<i>Jhar ber</i>	Cowpea, cucurbits, <i>guar</i> and Indian bean	Cowpea, <i>guar</i> , green gram, moth bean, pearl millet and sesame
Irrigated	Bengal quince, Indian gooseberry, Indian jujube and Indian mesquite	Guava, kinnow, <i>karonda</i> , lime, pomegranate and sweet orange	Brinjal, chilli, cole crops, cucurbits, garlic, okra, onion, peas, root/leafy vegetables and tomato	Chickpea, greengram, groundnut and mustard

(*Aegle marmelos*), pomegranate (*Punica granatum*), *aonla* (*Emblica officinalis*) etc. and suitable silvi-components viz. *khejri* (*Prosopis cineraria*) were found better for crop diversification in arid region.

Advantages of agri-horti-silvi systems

- Produce multiple products such as food, fruit, fodder and forage needed for livestock, fuel wood, timber, and leaf litter needed for organic manure production.
- The fruit trees/vegetables not only provide nutritious food material required for a balanced diet but also provide additional income and employment.
- This is also the best practice for soil nutrient recycling, which also helps to reduce chemical fertilizers purchase.
- Improve the farm site ecology by reducing soil erosion and nutrient loss.
- Improve the local micro-climate and enhance the farm productivity.

Management practices of agri-horti system

The management practices of horticultural crops were standardized for optimizing the productivity of agri-horti system. Suitable rootstocks for improved cultivar of *ber* were identified. Biofertilizer inoculation of *ber* seedlings recorded improved growth and nutrient uptake. Seed treatment of *Cordia myxa* seed with GA (250 and 500 ppm) improved the germination. Seed treatment of *karonda* with treatment of GA and of

Emblica with 1% KNO₃ improved the germination. In some of indigenous fruit plants, the vegetative propagation techniques were standardized. In *kair* (*Capparis decidua*) hardwood cutting planted in July–August gave better rooting (30 to 40%). *Cordia myxa*, I-budding gave highest success between July and September.

Selection of suitable species: It is one of the important management aspect on which success of agri-horti-silvi system relies. Any such selection is based on a number of important characters of the species, such as fast growth rate, multipurpose, tolerance to drought and extremes of temperature, less competition for soil moisture, less allelopathic effect, faster rate of litter decomposition etc. Model tree for agri-silvi system showed fast vertical growth, a small crown, a loose canopy, straight and clean bole, a high proportion of main stem in the overall biomass and deep and deciduous root system. Trees with a small crown require little horizontal space hence offer a larger density to annual crops. Consequently, returns per unit area are higher. A loose canopy permits light transmittal and less interference with the crop. Straight-growing trees, occupying less horizontal space and thus interfere less with the growing crop. Straight and clean boles provided quality wood that, in addition, is easier to handle in wood processing. The root system in agroforestry trees must be deep. This is more important in dry areas where moisture stress is common. The

Table 2. Grain and straw yields of moongbean and pearl millet with and without trees

Tree density (trees/ha)	Moongbean (kg/ha)		Pearlmillet (kg/ha)	
	Grain	Straw	Grain	Straw
with <i>Prosopis cineraria</i>				
417	153	1,666	133	4,330
278	162	1,699	141	4,430
208	193	1,803	158	5,420
with <i>Tecomella undulata</i>				
417	123	1,157	132	3,827
278	140	1,423	131	4,100
208	153	1,510	136	4,560
open field				
No. trees	180	1,720	165	5,470

shallow root system interferes in the usual agricultural operations, like ploughing, sowing, hoeing, of the annual crops. Thus, a deep root system is one of the major requirements of agri-silvi-horti systems. Several promising fruit crops/ trees like *Prosopis cineraria*, *Hardwickia binata*, *Tecomella undulata*, *Cordia dichotoma*, *Cordia gharaf*, *Zizyphus nummularia* var. *rotundifolia*, and *Z. mauritiana* are suitable for the area receiving rainfall <300 mm. Besides providing fruit, these plant produce moisture laded nutritious leaves for animal. Several other fruit such as *Emblica officinalis*, *Punica granatum*, *Citrus aurantifolia*, *Phoenix dactylifera*, and *Tamarindus indica* can be grown in the area having irrigation facilities.

Bael (*Aegle marmelos*) is also an adapted species for arid region but due to lateral root spreading, it competes for soil moisture with the annual crops and hence can be planted on boundaries in agri-silvi-horti systems or as sole plantations. Among the vegetable crops *Solanum melongena*, *Lagaria siceraria*, *Luffa acutangula*, *Luffa cylindrica*, *Citrullus lanatus*, *C. lanatus* var. *fistulosus*, *Cucumis melo* var. *utillimus*, *Cucumis melo* var. *momardica*, *Moringa oleifera*, *Cyamopsis tetragynoloba* and *Vigna unguiculata* are suitable for horticultural-based agroforestry systems. Some of the recommended agri-horti crops components for Indian arid regions are given in Table 1.

Appropriate tree density: The density of trees in arid region varies greatly from 5 to 250 trees/ha. It is

Table 3. Fertilizer schedule for fruit plants (N, P₂O₅ and K₂O in g/plant)

Fruit crops	1 to 3 years	4 to 6 years	7 to 10 years	>10 years
<i>Ber</i> (Grafted)	200-200-200	300-300-300	400-300-300	500-400-400
<i>Anar</i> (Pomegranate)	300-250-250	500-300-300	700-400-400	900-500-500
<i>Aonla</i>	100-75-100	200-150-200	300-800-1,000	400-1,000-1,200

lower in the dry south-western part (Jaisalmer) and higher in the semi-arid north-eastern part (Pali), but it rarely exceeds 50 trees/ha in the Thar desert itself. To obtain larger income it is mandatory to increase the present tree density from a present 10-40 trees/ha to about 100 trees. The density may also be increased by planting suitable tree species. The tree-crop interactions are largely affected by varying tree densities and different intercrops viz. moongbean, cluster bean, moth bean, and pearl millet. Studies conducted at CAZRI, Jodhpur, showed that during the establishment phase *P. cineraria* did not compete with the associated crops nor was its growth affected by the intercrops. At 4 years of age, 417 stems/ha (4 m × 6 m = 24 m²/tree) was found optimum density at 4 years of age. At a later stage, towards 10 years, the optimum density was found to be 208 trees/ha (Table 2) with *Techomella undulata*.

Tree canopy management: Proper management of tree and crops is vital for optimizing productivity of agri-silvi-horti system. In agri-silvi-horti system, trees interact with agricultural crops at above ground and below ground interfaces for growth resources like light, water and nutrients. The magnitude of negative interactive effects of trees on crops at above and below ground interfaces can be reduced through coppicing, pollarding, lopping and pruning. In general the farmers do not follow any set procedure for lopping/pruning of trees to obtain fodder/fruit yield. The intensity and frequency of lopping is not uniform. Sometimes the tree is also damaged by farmers during the lopping operations; hence the farmers suffer economic loss. Several studies showed beneficial effects of tree management on crop productivity. In an agri-silvi system comprising *Holoptelia integrifolia* (12-year-old plantations) and arid legume, the yield of *Vigna radiata*

was 25% higher under lopped tree than unlopped trees.

In *ber* the pruning of branches at 17 to 23 nodes on the main axis produce vigorous shoot with maximum fruit production. The main axis of the branches should be pruned keeping 15 to 25 nodes depending on climatic conditions i.e. 20 to 25 nodes in arid areas, and 15 nodes in semi-arid area along with complete removal of secondary branches. Leaf area index; dry matter production and crop growth rate of intercrops were lower in unpruned trees over pruned one. Higher yields of arable crops were obtained with increasing pruning frequency and decreasing pruning height. In case of *Phalsa*, pruning in last week of December at 120 cm from ground level was found at optimum.

Root pruning: Deep ploughing in alternate years for moisture conservation in the soil profile is a necessary operation for reducing the underground competition for water and nutrients. This also helps the removal of lateral roots of the trees/shrubs standing in agricultural fields and thus minimizes the competition with the associated crops. Increased production of moongbean, cluster bean and forage sorghum in association with established trees of *Acacia tortilis* was reported with pruning of roots by digging trenches along with rows of these trees.

Nutrient management: Application of fertilizer to agricultural crops in agroforestry system is an important management practice to obtain higher production. Young fruit plants should be manured during rainy season every year. A dose of 50 kg/tree farmyard manure should be incorporated in the basin with the onset of monsoon. Depending upon the age of plants canopy development, soil moisture availability, chemical fertilizers should be applied in 2-3 splits after a rainfall incidence or watered. An estimate of fertilizer to be applied to different fruit

plants is given in Table 3.

In arid environment, below ground resources are more limiting than the above ground resources that influence the growth and productivity of tree and crop both. Continuous depletion of nutrient from the lower layers of soil profile demands higher nutrient application to achieve optimum productivity. The recommended dose of fertilizer + additional dose of N (10, 20 and 30%) significantly increased the yield attributing parameters over recommended dose of fertilizer in both agri-horti (wheat + kinnow) and agri-silvi-horti (wheat + eucalyptus + kinnow) system at CCSHAU, Hisar. Agri-horti (wheat + kinnow) system produced significantly higher grain and straw yield of wheat (2.79 and 4.15 tonne/ha, respectively) than agri-silvi-horti system (1.46 tonne/ha and 2.26 tonne/ha respectively). An increase of 83.6 and 91.0% in straw and grain yield, respectively of wheat was observed under kinnow+wheat system than kinnow + eucalyptus+ wheat system.

Agri-horti-silvi systems for arid region

Ber based agri-horti-systems: In arid region, agri-horti system involving *Z. rotundifolia* + *V. radiata*/*V. aconitifolia*/*C. tetragonoloba* and *Z. mauritiana* + *Vigna radiata*/*C. tetragonoloba* were found environmental friendly and economically viable system even during drought years. Intercropping of legumes with *ber* orchard produced higher grain yield of intercrops by 5 to 20% over their sole cropping. Intercropping of annual crops with fruit trees provides the extra income to farmers when fruit trees are in their juvenile phase. Even during sub-normal year, when rainfall was 51% less than long-term average of 360 mm, the yield of greengram with *Ziziphus* sp. was reduced by 44% whereas under sole crop moong bean yield was reduced by 51%. The inventory of system showed that this agri-horti system can provide round the year supply of fodder for 5 goat/sheep ha⁻¹ and fuel wood for family of 4 members, besides efficient nutrient cycling and increase in

economic stability. The fruit yield from the inter-cropped system increased the net profit to ₹ 28,886. This showed that this agri-horti system minimizes the risk in arid and semi-arid regions and helps in imparting economic stability. This system is however, generally recommended for areas with rainfall more than 250 mm.

The moong bean sown under *ber* (*Ziziphus mauritiana* cv. *seb*) plantation produced 0.2 tonne/ha of grain and 0.8 tonne/ha quality *ber* fruits from same land unit even when seasonal rainfall was as low as 200 mm (Table 4), thus rendering a drought proofing mechanism to the system. The economics of this improved system indicated that in sole leguminous crop (moong bean) farming, the net profit per hectare was ₹ 4,800/ha however, in *ber* intercropping, the profit was to a tune of ₹ 8,000/ha.

To optimize productivity and profitability during pre-establishment phase of *ber* orchard under same agri-ecosystem under irrigated condition, the association of cluster bean-mustard and Indian aloe as a groundstorey component with *ber* cv. Gola were recommended. These crops were identified as low input and high returning crops giving net returns of ₹ 65,802 and ₹ 26,144 ha⁻¹, respectively. Among the different crop combinations, the highest yield of *ber* was recorded with Indian aloe (13.55 q ha⁻¹) whereas with groundnut-wheat and cluster bean-mustard, the yield level was almost at par (9.62 and 9.80 q ha⁻¹) and minimum yield was recorded under sole plantation (8.09 q ha⁻¹). The average yield of ground storey crops over two years was recorded as 3.48, 50.97, 10.05, 11.49 and 20.48 q ha⁻¹ in groundnut (dry pods), cluster bean (green pods), wheat and mustard (grain) and Indian aloe (green leaf pads), respectively.

In another study conducted during

establishment phase of agri-horti systems under highly arid situation at Pugal (Bikaner), the highest total income and net profit was realized with *bael* + groundnut intercropping followed by *ber* + groundnut and kinnow + groundnut under irrigated conditions. The highest B:C ratio was recorded with *bael* + cluster bean followed by *bael* + moth bean (Table 5).

Khejri-based agri-silvi system: *Prosopis cineraria*, commonly known as *khejri* is regarded as a 'Kalpvriksha' of the Indian desert. This heavenly tree has mono-layered canopy and deep root system and provided nutritious edible pods and fuel wood to the human beings, nutritious forage to the animals and fertility to the poor soils. Farmers usually grew pearl millet, moth bean and cluster bean between the scattered *khejri* trees in the arid region. Maximum net return (₹ 15,197 ha⁻¹) and benefit-cost ratio (3.73) were obtained when pearl millet in *kharif* was followed by *toria* in *rabi* between the *khejri* trees in Haryana. Yield of fodder crops during both *kharif* and *rabi* was higher in association with *khejri* trees sole cropping. Under irrigated condition, about 86% higher grain yield of barley in association with *khejri* was registered. Besides, the yield of chickpea also improved soil fertility and moisture conservation.

Pomegranate based agri-horti systems: Pomegranate is another important crop of arid region. Farmers generally grew the crop under sole fruit garden. To improve the productivity of 10 years orchard of pomegranate, annual legumes were incorporated. The seed yield obtained in inter-cropping system (green gram, moth bean and cluster bean) was lower than that of sole cropping, but the fruit yield obtained from trees increased the net profit of agri-horti systems in monetary terms. The highest cluster bean equivalent seed

Table 5. Economics of different agri-horti system during establishment phase at Pugal (Bikaner)

Agri-horti system		Net profit (₹ ha ⁻¹)	B:C Ratio
<i>Ber</i> +	Moth bean	10,854	2.06
<i>Ber</i> +	Cluster bean	12,970	2.33
<i>Ber</i> +	Ground nut	20,379	2.45
<i>Bael</i> +	Moth bean	14,310	2.86
<i>Bael</i> +	Cluster bean	16,054	3.92
<i>Bael</i> +	Ground nut	21,799	2.75
Kinnow +	Moth bean	11,015	2.20
Kinnow +	Cluster bean	11,122	2.10
Kinnow +	Ground nut	19,830	2.50

yield (4,550 kg ha⁻¹) was recorded with the intercropping of green gram + pomegranate, which was 71.56% higher over sole green gram. Intercropping of moth bean with pomegranate was observed next best combination for increasing cluster bean equivalent seed yield. Intercropping of green gram + pomegranate fetched highest net returns (₹ 2,22,950) and benefit cost ratio (4.86). This was because of higher production of seed yield of green gram and higher market value of pomegranate fruit. Mothbean + pomegranate was the next best combination for realizing higher monetary benefit and benefit-cost ratio.

Aonla-based agri-horti systems: *Aonla* is one of the important adapted fruit crops of arid region. Despite its adaptability in arid climate, productivity and economic return of the crop are affected by low temperature (- 2°C) and frost, which cause economic loss to the growers. To mitigate the risk of total crop failure, suitable crop combinations were evaluated in the interspace of *aonla* orchard at Central Institute for Arid Horticulture, Bikaner between 2004 and 2008, which could generate extra income and improve productivity of the region. Moth bean grown *kharif* was a common ground storey crop grown in rotation with *rabi* crops i.e., fenugreek, chickpea, mustard and cumin. Higher grain and straw yield were recorded in moth bean-chickpea (497 and 1,250 kg/ha) and moth bean-fenugreek (465 and 1,161 kg/ha) crop sequence. Amongst the *rabi* crops, grain yield of fenugreek, chickpea, mustard and cumin were

Table 4. Production potential of *ber* and moong bean agri-horticulture system with 200 mm annual rainfall in arid region.

Treatments	Annual rainfall (mm)	<i>Ber</i> fruit yield (kg/ha)	Moong bean Grain yield (kg/ha)	Net profit (₹/ha)
Sole crop	200	-	520	4,800
Intercropped with <i>ber</i>	200	800	200	8,000



Fig. 3. Bael + Aloe vera agri-horti system



Fig. 4. Shisham + greengram agri-silvi system



Fig. 5. Citrus + greengram agri-horti system

higher by 28.05, 38.11, 19.96 and 36.05%, respectively, when grown in association with *aonla* than sole crops. The highest net profit (₹ 28,260/ha) was obtained from moth bean-cumin cropping system, followed by moth bean-chickpea (₹ 25,024/ha) cropping system. Moth bean-chickpea intercropping with *aonla* supplemented 22.01, 5.00 and 27.90 kg/ha nitrogen, phosphorus and potassium (N,P,K) through crop residues, followed by moth bean-fenugreek crop sequence.

The multistorey production system of *aonla-ber-brinjal-moth bean-fenugreek* and *aonla-bael-karonda-moth bean-chickpea* showed that ground storey crops did not affect the growth of over storey crop and *vice-versa* and these systems were promising under arid conditions of Rajasthan. The net return obtained from above cropping through ground storey crop during first year was to the tune of ₹ 23,614 and 25,662 ha⁻¹, respectively, which increased up to 20 and 15%, respectively, in second and third years. This indicated that during juvenile phase of fruit tree, there are ample opportunities for raising annual, biennial and perennial crops which can meet diversified need of farmers.

Kinnow is an important fruit crop in Hanumangarh and Sriganganagar districts of Rajasthan. The study conducted in kinnow based agri-horti system under irrigated arid condition at Sriganganagar showed that intercrop did not show any significant negative effect on fruit yield. The yield was highest under moong bean and lowest under cotton intercropping. The fruit yield was at par with intercropping of moong bean, cotton-barley and cotton-chickpea.

Citrus-based agri-horti system: It is further classified as sprinkler irrigated system and drip irrigated citrus with rainfed crops. Sprinkler Irrigated System. In 8-year-old agri-horti-silvi system comprising citrus (*Citrus aurantifolia*), mopane (*Colophospermum mopane*) and shisham (*Dalbergia sissoo*) as tree component and green gram-mustard as intercrop were tested with sprinkler irrigation system. Green gram intercropped with citrus produced 60.5 and 22.8 % higher seed yield over the intercrops (Fig. 5) with mopane and shisham, respectively (Fig. 4). Similarly, mustard intercropped with citrus (Fig. 1) produced 64.7 and 12.7 % higher seed yield as compared to intercropped with mopane and shisham, respectively. Citrus-greengram-mustard improved the system productivity in citrus equivalent yield by 78.6 and 70.6 %, over mopane and shisham, respectively. The eight years study showed higher system productivity by citrus-based intercropping system without any reduction in crop yield. Mopane and shisham showed more competitive effect on intercrops than citrus. Intercropping of mustard with citrus increased the grain yield of mustard by 59.61% (Fig. 1.) over mopane and 28.49% over shisham, respectively.

Drip irrigated citrus with rainfed crops: Efficient utilization of limited irrigation water is one of the major concerns in the arid region. Drip irrigation system proved efficient in water saving as well as applying the water very judiciously to the root zone of trees. During the initial years of orchard establishment, the fruit trees are not in production. Therefore the farmers are not getting any income from the fruit trees

(orchards) during first few years. For getting the income from this system, growing of low water requiring rainfed intercrops with fruit trees becomes the source of income to the farmers. Three horticultural trees (*citrus*, *bael* and *gonda*) showed that the fruit yield of citrus with intercropping of rainfed moth bean was 13.77 and 55.41 % higher than compared to intercropping of cluster bean and *sonamukhi* (*Cassia angustifolia*), respectively at CAZRI, Regional Research Station, Bikaner. Similarly, moth bean intercropped with citrus produced highest grain and straw yield (361 and 1,352 kg/ha, respectively) than cluster bean and *sonamukhi*. Intercropping of *Aloe vera* with *bael* under drip system proved more remunerative system over rest of intercrops (Fig. 3). The enhanced system productivity of rainfed moth bean intercropped with citrus was found under agri-horti systems of arid western Rajasthan.

SUMMARY

Indian arid zone agriculture showed fragile ecosystem with poor rainfall, frequent occurrence of drought, high temperature and poor soil resulting in failure of annual crops. The perennial fruit and silviculture trees provide an insurance against the complete crop failure having resistant to drought than crops. Agri-silvi-horti system provided more and multiple produce in one time from the same piece of land. The total system productivity is also higher than the sole cropping of crops or horticulture.

¹Head,^{2,4}Principal Scientists, Corresponding author's: e mail: narendra_yadava@yahoo.co.in