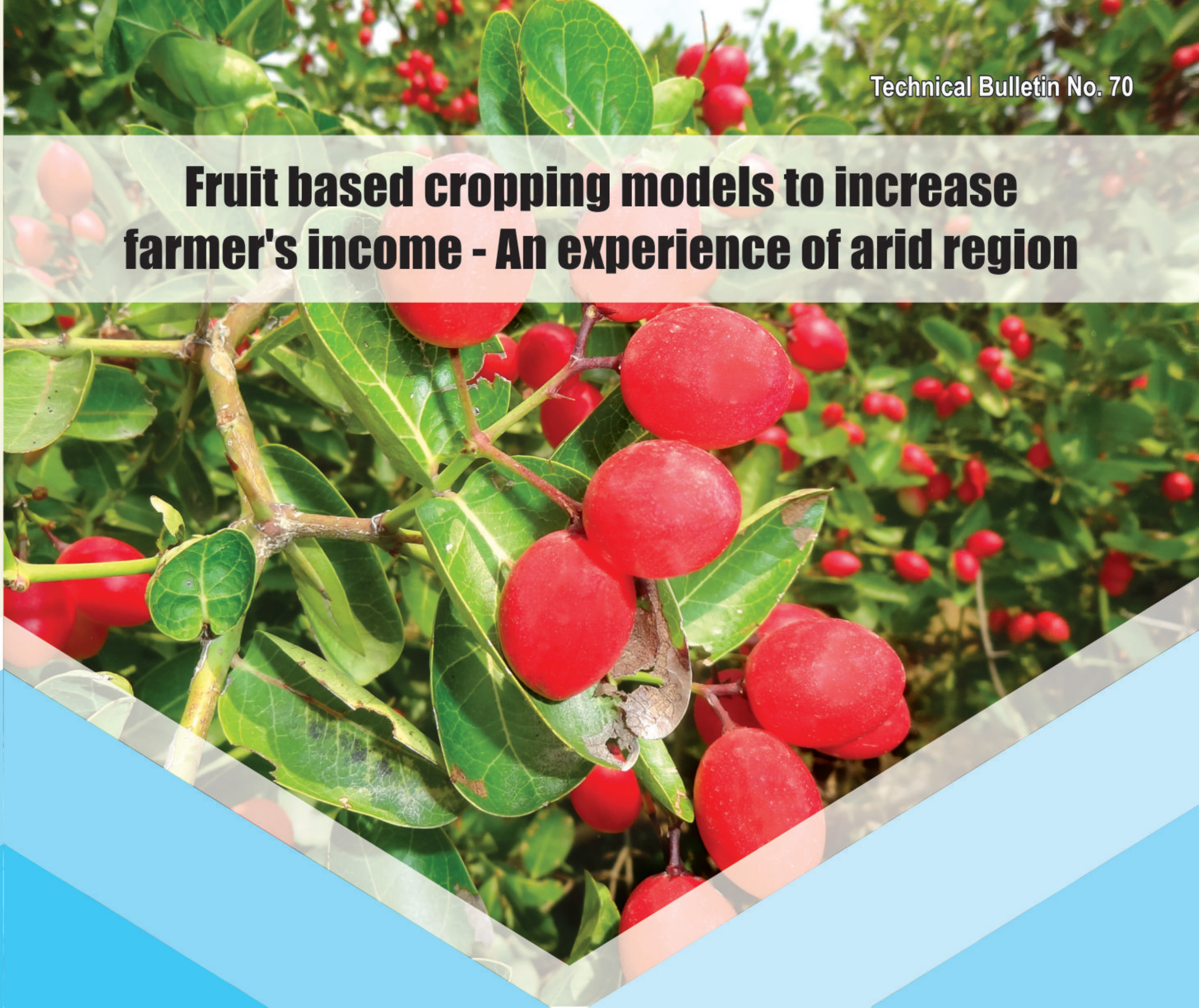

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PREFACE

In India, a vast land resource 31.7 mha (~9% of the total geographical area) falls under hot arid regions. Crop production in arid regions results in low, unstable and quite often uneconomic yield owing to various edapho-climatic constraints. The traditional farming systems, currently in vogue in arid regions of the country, are largely subsistence in nature and are need based. Besides, they are not necessarily efficient in utilization of resources for a given location. Challenges like frequent droughts, the increasing costs of cultivation, lower compensation of labour and inputs have also made farming in the arid regions a challenging enterprise. However, the largest section of the farming community is still dependent on farm related activities for their livelihood. On the other hand, useful technologies have been generated by researchers on some alternative land use systems, which could be adopted to improve farm income. Therefore, the farmers could benefit greatly by resorting to diversification in the farming systems. Diversification of farming systems not only ensure sustainable return from the field but it also, to some extent, combat global energy crisis by maximum utilization of natural resources like land, light and water.

Keeping in view the increasing knowledge in area of diversified cropping system in arid region, it was felt to bring out this technical bulletin to draw out a faithful response in researchers and growers. This bulletin contains the information on scientific adoption of diversified cropping models for increasing income of the farmers of the arid region. Information on selection of suitable crops, cultivars and varieties, appropriate propagation method, proper planting technique, development of micro-climate through wind breaks, moisture conservation practices, canopy management of perennial component etc. has been dealt with the help of ample numbers of pictures and tables for easy comprehension of the readers.

Authors

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Contents

1. Introduction

The projected population of India is likely to range between 1.64 and 1.74 billion by 2050, when the world population is likely to reach 9 billion. To feed this ever increasing population, the estimated demands by 2050 are likely to be 199 million tonnes of vegetables and 146 million tonnes of fruits; besides, other commodities. Similarly, the demand for another important horticultural commodity *i.e.* seed spices is predicted to be three fold of the current consumption by 2050. However, the land available for agriculture is shrinking due to increase in population pressure, urbanization and industrial growth. The average size of the landholding declined to 1.32 ha in 2000-01 from 2.30 ha in 1970-71. If this trend continues, the average size of holding in India would be mere 0.68 ha in 2020, and would be further reduced to a low of 0.32 ha in 2030 thus leaving scope for the cultivation of horticultural crops. A large chunk of marginal and waste land is however, available in arid regions which can be exploited for cultivation of horticultural crops so as to meet the demand of burgeoning population. In India, a vast land resource 39.54 mha (~12% of the total geographical area) falls under arid regions (Saroj *et al.*, 2004). The hot arid agro-eco region encompasses south-western parts of the states of Punjab and Haryana, western parts of Rajasthan, Kutchh peninsula and northern part of Kathiawar peninsula in Gujarat State (Fig. 1). The area accounts to 31.9 m ha, representing 9.78 per cent of the total geographical area of the country. Arid refers to prolonged dryness, and is used with regards to the climate itself, and the land below it. In such regions the ability to produce agricultural crops is limited (Chundawat, 1990). In general, on arid lands the potential evaporation of water from the land exceeds the rainfall. Arid environments are extremely diverse in respect of their land forms, soils, fauna, flora, water balances, and human activities. Crop production in arid regions results in low, unstable and quite often uneconomic yield owing to various edapho-climatic constraints. These constraints include high and low temperatures, low rainfall, low relative humidity, high potential evapo-transpiration, high sunshine, sparse vegetation and high wind speed during summer. The soils of arid region, particularly, are very poor in fertility. Most of arid areas (about 64.6%) are dunes where the soils often contain only about 3.2-4 per cent clay and 1.4-1.8 per cent silt. Soils are, usually, low in nitrogen, phosphorus and micronutrients like copper, zinc and iron. The soils often have high salinity. The water holding capacity of soil is also poor. This situation is further aggravated by soil moisture stress

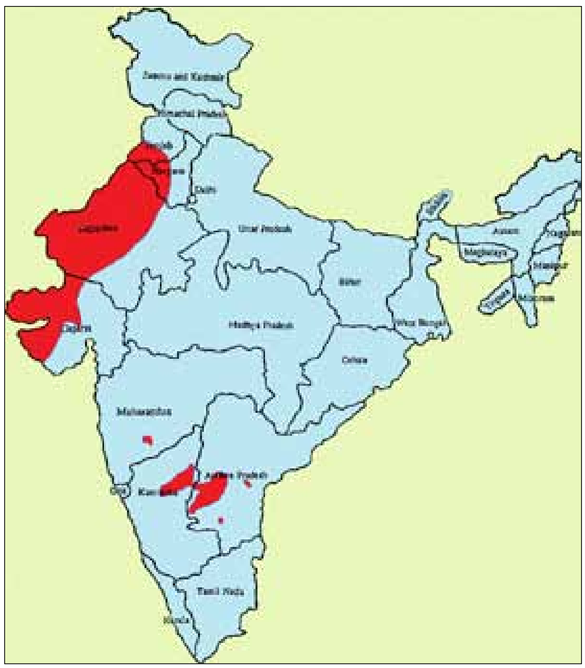

Fig. 1. Extent of arid regions across the country.

due to vagaries of weathers as the rate of evaporation surpasses the available moisture by 50-60 per cent and moderate to severe soil erosion, which contribute to low productivity in rainfed arid regions. The ground water resource is not only limited owing to poor surface and sub-surface drainage but is also saline in quality. The water resources in arid regions are limited and can irrigate hardly 4% of the area. In addition, the annual average rainfall in the Indian arid regions is very low and erratic and varies from 200 to 700 mm. Furthermore, there is often failure of monsoon leading to intermittent droughts causing shortage of food, fodder and fuel to the inhabitants (Saroj *et al.*, 2004).

The traditional farming systems, currently in vogue in arid regions of the country, are largely subsistence in nature and are need based. Besides, they are not necessarily efficient in utilization of resources for a given location. This leads to loss of precious natural resources, particularly, land. The traditional method of restoring the health of the poor dryland soils by giving a cultivation break of 2-3 years has been discontinued by majority of the farmers due to increased population pressure and farmers preference to short term gains over systems resilience (Kumar *et al.*, 2014). In addition, challenges like frequent droughts, the increasing costs of cultivation, lower compensation of labour and inputs have also made farming in the arid regions a challenging enterprise. Employment opportunities in sectors other than agriculture have tempted many to switch over to other non-agricultural job activities. However, the largest section of the farming community is still dependent on farm related activities to meet their livelihood. Further, due to high risk involved in crop production under arid conditions, farmers, in general, do not invest on agricultural inputs like fertilizers, fresh seeds and improved natural management practices, which results in further land degradation and poor soil health and decreased farm income (Jodha *et al.*, 2012). Under such scenario, perennials fruit tree based production system is considered effective strategy for improving productivity (Chundawat, 1993), employment opportunities (Pareek, 1999), economic condition and nutritional security (Chadha, 2002). Several drought hardy fruit crops like *Ziziphus mauritiana* (*ber*), *Z. rotundifolia* and *Cordia myxa* (*goonda*) are suitable for the area receiving annual rainfall 200 - 400 mm. Besides providing fruit, these plant produce moisture laded nutritious leaves for animal, some of them being very high in crude protein. Other fruits such as pomegranate and lemon could be grown in this extreme dry region having irrigation facilities (Pareek and Awasthi, 2008). Several useful technologies have been generated by researchers on many alternative land use systems, which could be adopted to improve farm income. Therefore, the farmers could benefit greatly by resorting to diversification in the cropping systems. Diversification of cropping systems not only ensure sustainable return from the field but it also, to some extent, help combat global energy crisis by maximum utilization of natural resources like land, light and water (Pareek *et al.,* 2008). Diversification of cropping systems with inclusion of perennial tree components can play a vital role in meeting the diverse needs of people resorting to them as inter-dependent benefits of the three components, *viz.* trees, crops and livestock in addition to the 6Fs, *i.e.* food, fruit, fodder, fuel, fertilizer and fiber from limited land resources. Trees are integral to our traditional farming systems, for the innumerable benefits that they provide (Handa *et al.,* 2016).

2. Need for diversification

Due to ever-increasing demand of food, fruit, fuel and fodder, cultivation has been extended to marginal and degraded lands. Marginal and small farms compose 75 per cent of land holdings of less than 2.0 ha. The soils are poor in and less fertile. Further, poor management of marginal lands results in further land degradation. These marginal lands of arid regions are not able to sustain arable crops in long run. In addition, the income generated from such a holding is inadequate to sustain the family. This is so due to frequent droughts and vagaries of monsoon. Therefore, there has been thinking to develop some alternate land use systems for these lands, which will help conservation of available moisture, prevent further land degradation, enrichment of biomass to the soil, improved availability of food, fodder and fuel as well as generation of employment opportunities to farming families round the year (Saroj *et al.*, 2004). The system would ultimately contribute to increase national production and bring prosperity to the farming communities. Therefore, there is no alternative but to integrate fruit trees with agricultural crops, which can withstand climatic aberrations and conserve the natural resources efficiently in order to meet aforementioned goals (Rao, 2009).

Benefits of fruit-based cropping

- Effective alternatives to the traditional mono cropping system for increasing the profitability.
- Self-sustainable system, where solar energy can be harvested at different heights, soil resources can be efficiently used.
- Good option for minimization of crop failure due to inclement weather.
- Provides the subsistence to farmers and appreciable amount of economic return even under unfavourable agro-ecological situations.
- Increased cropping intensity.
- Source of mineral nutrients for improving household nutritional security.
- Provides valuable bi-products like fodder and fuel wood through annual pruning apart from fruits. (Bammanahalli *et al.*, 2016).

Although, these lands have their own biophysical farming constraints but can be utilized efficiently on sustained basis for fulfilling the basic needs of food, fruit, fuel, fodder *etc.* through horticulture based cropping systems, such as agri-horticulture system (fruit based agro-forestry systems), by integrating practically feasible, economically viable and eco-friendly technologies. Tree component in arid agriculture increases production and income, besides imparting stability to the farming system. Fruit trees, apart from the above advantages also yield valuable bye-products like fodder, and fuel wood, through their annual pruning and fruits, which are supposed to improve and maintain good health of human beings (Awasthi and Singh, 2011). Agri-horticulture system or horti-pastoral system is one form of agro-forestry, where the tree component is a fruit tree.

To maximize available natural resources and assured farm return, inclusion of horticultural crops in farming system for diversification seems a viable proposition. Horticultural crops has knack of providing nutrition, income, employment and social security to the inhabitants of these areas as they are hardy and are able to give a satisfactory yield under aforesaid constraints.

3. Principles of cropping systems

1) Selection of crops should be made based on their ability to complement the component crop(s). This involves choosing those crops and systems, which share resources without causing nutrient deficiencies for neighbouring or subsequent crops *e.g.* plant nitrogen demanding crops may be taken up following N-fixing legume crops, for instances growing cluster bean in *kharif* followed by seed spices in *rabi*. Likewise crops, which respond to good soil structure, should follow soil-restoring crops. Crops with low nutrient requirement (*i.e.* leguminous) should be used at the end of a crop rotation when soil fertility levels are lowest.

2) Select crops and a cropping rotation which utilize available resources efficiently. Planning include choosing plants having different rooting depths with different nutrient uptake rates, different heights for even distribution of sunlight, different rooting patterns, varying plant structures, or different harvest times.

3) Choose crops and a cropping system, which maintain and enhance soil fertility. This includes the maintenance of nutrients such as nitrogen and carbon (organic matter). For instance, crop rotations with approximately 30-50% N-fixing crops, like legumes, generally do not deplete nitrogen in diversified cropping system. Similarly crops, which produce large amounts of organic matter both above and below ground such as perennial grasses should be selected. The crop rotation should include some deep rooted crops and crops that have large roots.

4) Select crops which have a diversity of growth cycles. An ideal cropping system would consist of rainy season and winter season annual field crops, pasture grasses and perennial trees, both deciduous and evergreen. However, crop combination should be such that it does not have any allelopathic effect irrespective of the crop combinations.

5) Choose a diverse species of crops. The more diverse the rotation, and the longer the period before the soil is reseeded with the same crop, the more likely weed, pest and disease problems will be avoided. Trying to grow too many crops however, may cause management problems; therefore not more than 6-7 annual crops should be planted (unless the farmer has efficient management skills). For example;

   i. Typically it is a good idea to rotate between grass and broad leaf crops for disease prevention.

ii. Changing the field each year between grass family plants and broad leaf plants helps reduce the carryover of pathogenic disease organisms from year to year.

iii. For some disease susceptible crops, it is advisable not to grow the same crop on the same field for 3 years after the last planting.

6) Keep the soil covered with low growing crops. Efforts should be made to grow sequences of crops that maximizes capture of solar radiation and minimizes the risks of soil erosion.

7) Plan and modify cropping system keeping in view the dynamics of changing requirements. Diversified cropping systems calls for an effective and timely management of available resources at farm. One need to consider entire farm planning goals, including: household food security, income generation needs, livestock feed requirements, labour and management skills. One may also need to make adjustments for the prevailing weather and market conditions as the cropping year progresses.

8) Regular monitoring farm progress by making plans and keeping records. Learning from past experiences can result in more efficient crop production.

4. Constraints in adoption of fruit based multiple cropping systems

Expectations from perennial tree based cropping system are high in India in both rural and urban areas, which encompass production benefits that are in harmony with the ecology, environment, traditions and heritage of the country (Chinnamani, 1993). However, despite the fact that various researches have clearly demonstrated the potential of fruit tree based cropping system in different parts of the country, its adoption so far had been limited. The vast potential of such cropping systems remains largely underexploited, hitherto. This situation is a result of the interplay of several complex factors, which are listed below;

- Interference of fruit trees decreases the ground storey crop yield at later stages due to competition for available resources, particularly, for light as tree canopy absorbs maximum sun light. Likewise, few perennial trees exert competition for moisture and nutrient through their profuse lateral roots.
- Varying temporal requirement of perennial and annual component crops sometimes disturb physiological need of each other. For instance, rest period of a perennial tree may coincide with critical stage of irrigation of annual crop. Likewise, intercultural operation of one crop may damage root of other crop component.
- The understanding of the biophysical issues related to productivity, water resources sharing, soil fertility, and plant interactions in mixed communities is incomplete and insufficient, mainly because research has mostly been observational in nature rather than process oriented (Sharma *et al*., 2009).

- Labour is one of the major constraints in multiple cropping systems as cultivation practices are continuously followed in one or other crop throughout the year.
- One crop may serve as a host of insect-pest/ disease of another component crop. Similarly, tree crops attract the birds, which may results in increased damage to food crops.
- Longer period is required for trees to come into bearing. This causes delay in returns due to longer gestation period of perennial fruit trees, which is one of the reasons of need for diversification in cropping system.
- Allelopathic effect by tree crops on annual food crops (Saroj *et al.*, 2002, Awasthi *et al*., 2005, 2008).
- Reluctance among farmers to displace food crops with perennial trees, especially, where land is limited.
- Lack of awareness to adopt fruit tree based cropping (Saroj *et al.*, 2004).

5. Suitable crops and varieties

The fruit based cropping system comprises three main components *viz*., Overstorey main crop & component perennial crops and understorey intercrop.

i. Main Crop: Main crops are the perennial fruit species having a larger canopy size and prolonged juvenile as well as productive phase. Generally the crops utilize the land up to 20-25 years, whereas only 25-30 per cent of land is effectively used up by the main crop for 10 years. These plants are planted at wider spacing.

The fragile environmental conditions of arid regions cause extreme degree of moisture stress, which has its toll on crop productivity. In addition, the crop productivity is further lowered by the poor fertility and water holding capacity of soils. Under such hostile growing conditions, profitable cultivation of agricultural crop has limited scope. However, some perennial fruit crops can be grown successfully with suitable scientific interventions (Hiwale *et al.,* 2007). Therefore, fruit species and cultivars selected for this region should possess the following ideotype

1. Deep root system as in *ber, aonla, Cordia,* mulberry in order to escape/tolerate drought conditions.
2. Leaf fall and dormancy during summer as in *ber* and *aonla*, which helps to cut water loss and protect from desiccation injury.
3. Characters which help to conserve water in the plant, such as high sap density in fig, waxy coating on leaf surface and pubescence on lower leaf surface as in *ber* and sunken stomata in *goonda*.
4. Maximum period of vegetative growth and development coinciding with the monsoon period as in *ber* and *aonla*.

5. In addition to above for inclusion in diversified cropping system, the fruit trees should also have branching habit, which allows light penetration to the understorey intercrops and their leaf litter decomposition or root exudates should not have any negative impact (allelopathy) on growth of understorey crops (Saroj *et al.*, 2002).

Fruit trees in arid zones perform several functions, some of which are described below:

a. They can act as a soil stabilizer and prevent water and soil erosion. They also protect the soil better than annual plants. Their extensive roots system improves the soil, and the shade they provide facilitates sustenance of ecosystem. These functions are essential for ensuring the soil stability and the continuity of agricultural activities.

b. They are an important source of forage for livestock and wildlife at a time when herbaceous fodder is not available for instance *ber,* fig, mulberry *etc*. (Table 1).

c. They are a source of wood products, including fuel-wood, poles, and lumber. Fuel-wood is domestic fuel, not only in the rural areas but also in some urbanized areas. Wood is also used as a construction material. These include *ber* and *jamun*.

d. They are a source of foodstuff for the population. Many fruits, leaves, young shoots, and roots provide valuable food in the dry season and, therefore, comprise an important reserve for emergencies.

e. They are a source of non-woody products. Many trees and shrubs yield products, which are important for everyday use by the inhabitants, for industry, and at times, for export. For example, a variety of trees are characterized by a high content of tannin (utilized by the leather industry) in their bark or fruit. In Burma, the *ber* fruit is used in dyeing silk. The bark yields a non-fading, cinnamon-colored dye in Kenya. Other trees and shrubs yield fibers, dyes, and pharmaceuticals. The pollen of many fruit plants is used for honey production (beekeeping). Similarly, The Indian jujube is one of several trees grown in India as a host for the lac insect, *Kerria lacca*.

Criteria for selection

1. Easy to establish
2. Root system and root growth should be able to exploit deeper soil layers than those tapped by the under and ground storey crops.
3. Good cropping capacity
4. Branching habit, which allows light penetration to the under storey crops.
5. Crop should have strong coppicing and possess self-pruning properties or should respond to pruning.
6. Leaf fall during the growth period of the ground storey crops.
7. The litter decomposition should have positive effect on soil fertility.
8. Palatable foliage with high protein content.
9. Fast growing and high biomass production
10. Tolerant to biotic and abiotic stresses
11. Ability to withstand browsing / grazing
12. Reproductive phases coincides with the period of moisture availability (Saroj et al., 2004; Awasthi et al., 2007).

Table 1. Top feed fruit species of Rajasthan and their palatability rating*.

Fruit crops	Crude protein	Preferred animal	Palatability rating
Ber (*Z. nummularia*, *Z. mauritiana*)	12.9-16.9	Goat, sheep, camel	Good
Pilu (*S. oleoides*)	9.6	Camel	Good
Goonda (*Cordia myxa*)	-	Goat, sheep, camel	Moderate
Bael (*Aegle marmelos*)	-	Goat, sheep, cattle	Good
Drumstick (*Moringa oleifera*)	-	Goat, sheep, cattle camel	Good
Khejri (*P. cineraria*)	13.9	Goat, sheep, cattle camel	Good
Ker (C. decidua)	-	Goat	Moderate

** Adopted from Kumar (2016).*

The perennial fruit trees form prime component of the cropping system. Though, there are several fruit crops, which can be brought into cropping system, *ber* or Indian jujube seems to be most apt choice as it can do well even under marginal growing conditions and provides quality yields at low cost. Cultivation of *ber* under the harsh conditions of arid regions demonstrates its adaptation to desert conditions. Flowering and fruiting of *ber* coincide with the availability of maximum rain water (monsoon rains. It has a long tap-root and can withstand high temperatures during the summer (Krishna *et al*., 2014). During the dry hot summer, it undergoes dormancy by shedding its leaves, thus evading the injury of drought. It can produce fruits even under rainfed situation, with average annual rainfall of 150-200 mm. The tree propagates easily and greatly resists stress conditions in regions experiencing recurrent droughts. It is thus an important tree suitable for integration into the fruit based cropping systems in the warm desert eco-regions. The tree can provide economic sustenance to the region and insurance against ecological degradation. The suitable *ber* varieties recommended for cultivation are Gola, Seb, Umran, Mundia, Kaithali *etc.*

ii. Component Crops: There are several fruit species, which can be grown in association with the main crop thus diversifying the cropping system as per the requirement of grower. They could be filler crop as well and may be grown only during the juvenile phase of the main crop and uprooted at later stages.

Table 2. Suitable cultivars/varieties of different fruits crops.

S. No.	Fruit crop	Variety
1.	*Ber*	Gola, Seb, Kaithali, Mundia, Chhuhara, Umran, Goma Kirti, Thar Bhubhraj, Thar Malti
2.	*Bael*	NB-5, NB-9, Thar Neelkanth, Goma Yashi
3.	*Aonla*	NA-7, Goma Aishwarya, Kanchan, Krishna
4.	Mulberry	Thar Lohit, Thar Harit
5.	*Karonda*	Pant Manohar, Pant Sudarshan, Thar Kamal, Maru Gaurav
6.	*Lasoda*	Thar Bold, Maru Samridhi
7.	*Phalsa*	Thar Pragati
8.	*Khejri*	Thar Shobha
9.	*Pilu*	Local
10.	*Ker*	Local

The other important fruit crops, which can be grown along with *ber* in arid regions as component tree, are *aonla* (*Emblica officinalis*) (in frost-free area), *phalsa* (*Grewia subinequalis*), *karonda* (*Carissa carandas*), *goonda/lasora* (*Cordia myxa*), mulberry (*Morus* sp.), fig (*Ficus* sp.), *bael* (*Aegle marmelos*) etc.

iii. Groundstorey intercrop: The other component of fruit tree based cropping system is annual crops, which are grown in the interspaces. The intercrop occupies the lower most strata of the system and is grown in the unused interspaces between tree rows.

Criteria for selection

1. Early maturing/ short duration.
2. Dwarf and spreading type.
3. Better soil binding capacity, thereby resisting erosion.
4. Preferably, leguminous groundstorey crops, which have nitrogen fixing capacity (Saroj *et al.*, 2004; Awasthi *et al.*, 2007, Hiwale *et al.*, 2006).
5. High yield and quality.
6. Tolerance suiting the amount of available solar radiation.
7. Non competetive with the perennial companion crop.
8. Not to be more susceptible than the main crop to diseases they have common. Preferably, tolerant to biotic and abiotic stresses
9. Minimum tillage/intercultural operations, which would not damage the main crop or induce soil erosion or damage soil structure.
10. Suit the local labour, irrigation and market/processing facilities.

- Crops with companion and synergistic attributes are considered compatible to accentuate early income, optimize land use efficiency, facilitate better harness of solar energy, reduce the soil erosion, increase biological efficiency both in time and space dimensions in fruit based production systems (Bhandari *et al.*, 2014). In general, the intercrops are the location specific annual crops, selected as per the climatic and socio-economic suitability. These could be vegetables, pulses & legumes, oil seed, fodder crops, medicinal plants and seed spices. Among the vegetable crops, cucurbits like mateera (*Citrullus lanatus*), ridge gourd (*Luffa acutangula*), sponge gourd (*Luffa cylindrica*), bottle gourd (*Lagenaria siceraria*), long melon (*Cucumis melo* var. *utilissimus*), snap melon (*Cucumis melo* var. *momordica*), round melon (*Parecitrullus fistulosus*), *kachri* (*Cucumis* spp.), and legumes such as cluster bean (*Cyamopsis tetragonoloba*) and cowpea (*Vigna unguiculata*) can be taken successfully. Similarly, *kharif* pulses such as moth bean (*Phaseolus aconitifolius*), *urd* (*Phaseolus aureus*) and chick pea (*Cicer arietinum*) can be raised as they are able to withstand extreme aridity. Rapeseed (*Brassica campestristoria*) and mustard (*Brassica campestris*) are important oil seed crops, which can also be included in *ber* based cropping system. Pastoral Crops such as *sewan* (*Lasiurus sindicus*), *anjan* (*Cenchrus ciliaris*), *dhaman* (*Cenchrus setigerus*) and *karad* (*Dichantnium annulatum*), which grow naturally in pasture lands and rangelands, are suitable choices. The medicinal plants e.g. *gwarpatha* (*Aloe barbadensis* Mill.), *tumba* [*Citrullus colocynthis* (L.) Schrad], *senna* (*Cassia angustifolia* Vahl.), *guggal* (*Commifera wightii*), *dhatura* (*Datura stramonium* L.), castor (*Ricinus communis*), *heena* (*Lawsonia inermis*) etc. can also be grown in interspaces of *ber* trees. Likewise, seed spices like fenugreek (*Trigonellafoenum graecum*), cumin (*Cuminum cyminum*), chilli (*Capsicum frutescens*), coriander (*Coriandrum sativum*), fennel (*Foeniculum vulgare*), *etc.* (Table 3) can bring extra income to farmers. Exhaustive crops like maize, wheat, sugarcane, cotton, *etc.* are not appropriate choice and hence not recommended (Bhandari *et al.*, 2014).

Table 3. Suitable arid vegetables, spices and legumes for inclusion in fruit based cropping systems along with their cultivation requirement.

Crops	Varieties	Seed rate	Season	Row to Row x plant to plant distance	Yield
			Vegetables		
Clusterbean	Bhadavi	8-12 kg/ha	*Kharif*	45 x 20 cm	80-110 q/ha
Kachri	AHK-119	0.5 to 1 kg/ha	*Kharif*	200x 50 cm	95-100 q/ha
Snap melon	AHS- 82	0.5 to 1 kg/ha	*Kharif*	200 x 50 cm	225-230 q/ha
Indian bean	Thar Maghi	4-5 kg/ha	*Kharif*	200 x 20 cm	1.73 kg/plant
Mateera	Thar Manak	4-5 kg/ha	*Kharif*	200 x 50 cm	460-500 q/ha
Bottle gourd	Thar Samridhi	4-5 kg/ha	*Kharif*	200 x 50 cm	240-300 q/ha.

Crops	Varieties	Seed rate	Season	Row to Row x plant to plant distance	Yield
		Seed spices			
Fennel	PF-35, Gujarat Fennel-1, Ajmer Fennel-1, RF-101, RF-125, RF-143	10-12 kg seed/ ha (direct sown crop); 4-5kg/ha (transplanted crop)	*Rabi*	40-60 x 20-30 cm	15-25q/ha
Coriander	Narnaul Selection Pant Haritima Ajmer Coriander-1, RCR-41, RCR-435, RCR-436, RCR-684, RCR-446, Gujarat Coriander	10-12 kg per hectare (Spice Crop) 10-15 kg per hectare (Green Leaves), 20 kg /ha (rainfed crop)	*Rabi*	20-30 x 10-20 cm	15-20q/ ha. under irrigated and 6-8 in the rainfed.
Fenugreek	Pusa Early Bunching Kasuri Ajmer Fenugreek-1, Ajmer Fenugreek-2, Ajmer Fenugreek-3, RMT-143, RMT-305, Rajendra Kranti	Desi – 30 -25 kg/ ha. Kasuri– 10 kg/ ha	*Rabi*	20-25 x 10 cm	Local; 15-20 q/ ha, Kasuri: 6-8 q/ha
Cumin	RS-1: RZ-19, RZ-209, RZ-223, Gujarat Zeera-3 and Gujarat Zeera-4	10-16 kg per ha (line sowing); 15-20 kg/ha (broadcasting)	*Rabi*	20-30 x 10 cm	8-10/ha
		Legumes			
Groundnut	T.G. 37-A, TBG-39, HNG-10, Chandra and M-13	60-80 kg/ha	*Kharif*	30X10-15 cm	24-32 q/ha
Guar	HG-37, RGC-936, RGC-197, RGC-986, RGC-1017, RGC-1002, RGC-1003	15 to 20 kg/ha	*Kharif*	30X10-15 cm	12-16 q/ha
Moong	SML-668, MUM-2, RMG-62, K-851, RMG-492	12 -15 kg/ha	*Kharif*	30X10-15 cm	12-16 q/ha
Moth	RMO-40, RMO-257, RMO-225, RMO-435, RMO-423	10-12 kg/ha	*Kharif*	30X10-15 cm	12-16 kg/plant

The dwellers of the arid region have evolved several perennial tree based farming systems as a drought protective mechanism based on centuries old experience, descending from one generation to other (Rao *et al.*, 2018). The major components of traditional fruit based cropping systems in various districts of Arid Western Rajasthan are presented in Table 4.

Table 4. Components of traditional agroforestry systems in various districts of Arid Western Rajasthan.

District	Main tree/shrub	Main crops#	Major grass
Ganganagar and Hanumangarh	*Prosopis cineraria, Acacia nilotica* sub sp. *indica, Acacia tortilis*	Pearl millet, *moong* bean and cluster bean (rainfed). Wheat, cotton, rice and moong bean (irrigated)	*Lasiurus sindicus*
Bikaner	*Prosopis cineraria, Ziziphus nummularia, Calligonum polygonoides, Acacia jacquemontii*	*Moong* bean, moth bean, cluster bean and pearl millet	*Lasiurus sindicus*
Jaisalmer	*Calligonum polygonoides, Ziziphus nummularia, Prosopis cineraria, Acacia senegal, Capparis decidua*	*Moong* bean, pearl millet and cluster bean	*Lasiurus sindicus*
Barmer	*Prosopis cineraria, Tecomella undulata, Ziziphus nummularia, Capparis decidua*	Pearl millet, *Moong* bean and cluster bean	*Lasiurus sindicus, Cenchrus ciliaris*
Jodhpur	*Prosopis cineraria, Ziziphus nummularia, Capparis decidua, Acacia senegal*	Pearl millet, *moong* bean and cluster bean (rainfed). Wheat, chilli, mustard and *moong* bean (irrigated)	*Cenchrus ciliaris*
Churu, Jhunjhunu and Sikar	*Prosopis cineraria, Gymnosporia montana, Ziziphus nummularia*	Pearl millet, *moong* bean and cluster bean	*Lasiurus sindicus, Cenchrus ciliaris*
Nagaur	*Prosopis cineraria, Acacia nilotica*	Pearl millet and *moong* bean (rainfed). Wheat, *moong* bean and mustard (irrigated)	*Cenchrus ciliaris*
Jalore	*Prosopis cineraria, Salvadora persica, Salvadora oleoides, Acacia nilotica, Punica granatum*	Pearl millet, *moong* bean, *isabgol*, sorghum and cumin	*Cenchrus ciliaris*
Pali	*Salvadora* spp., *Acacia nilotica* sub sp. *indica, Acacia nilotica* var. *cupressiformis, Acacia leucopholea, Acacia catechu*	Sorghum, pearl millet, *moong* bean and cluster bean	*Cenchrus ciliaris, Cenchrus setigerus*

 # All the crops are rainfed, except otherwise indicated.
** Adopted from Rao et al. (2018).*

Besides, researchers have proposed various suitable horticultural crop combinations for agricultural production system under arid regions (Table 5).

Table 5. Crop components for cropping system in the hot arid region.

Rainfall	Over storey crop	Under storey crop	Ground storey			Microwind Break/ biofence
			Vegetable	Agronomic crop	Grasses	
Rain fed (rainfall < 150-300 mm)	*Khejri* (*Prosopis cineria*), *Ber* (*Ziziphus mauritiana*)	*Ber, Ker*	*Mateera* (*Citrullus lanatu*), *Kachri* (*Cucumis melo*), snap melon (*Cucumis melo var. momordica*), *tumba* (*Citrullus colocynthis*)	*Guar* (*Cyamopsis tetragonoloba*), *moth* (*Vigna aconitifolia*), *Bajra* (*Pennisetum glaucum*), *til* (*Sesamum indicum*)	*Cenchrus* sp., *Lasirus sindicus*	*Ker* (*Capparis decidua*), *Phog* (*Calligonum polygonoides*, *Khimp* (*Leptadenia pyrotechnica*), *Jharber* (*Z. nummularia*)
Rain fed (rainfall < 300-500 mm)	*Ber, lasoda* (*Cordia myxa*), *khejri*	Drumstick (*Moringa oleifera*), *Lasoda*	*Mateera, kachri,* snap melon, *tinda* (*Benincasa fistulosa*), brinjal, Indian bean, Clusterbean, cowpea	*Guar, moth, bajra, til*	*Cenchrus, Dicanthium, Pannicum*	*Ker, Khimp, Jharber*
Irrigated	Datepalm, *Ber, aonla* (*Emblica officinalis*)	Lime, guava, pomegran-ate	Cucurbits, chilli, tomato, brinjal, cole crops, peas, beans, onion, okra and leafy vegetables	Cumin, Isabgol (*Plantago ovata*), groundnut, mustard		*Lasoda,* drumstick, *Karonda* (*Carissa carandus*)

** Adopted from Bhandari et al. (2014).*

A Model lay out of the plan of the fruit based diversified cropping system is as followed;

X	***		***	X
++	***		***	++
++	***		***	++
++	***	O	***	++
++	***		***	++
++	***		***	++
++	***		***	++
X	***		***	X
++	***		***	++
++	***		***	++
++	***	O	***	++
++	***		***	++
++	***		***	++
++	***		***	++
X	***		***	X

X *Aonla* O *Ber* ++ Brinjal *** Moth bean *** Cumin

6. Agro-techniques

i. Wind break and shelter belts

In arid region, wind of high velocity during summer and cold chilling winds during the winter months often creates disaster to the orchard. Hence an effective windbreak with tall and compact trees should be established in the orchard along with fence across the direction of the wind at suitable intervals in the orchard in order to give effective protection to the fruit trees (Fig. 2a and 2b).

Advantages of windbreaks

a. Windbreaks reduce the wind velocity and minimize the damage to fruit trees.

b. They minimize the adverse effect of high and low temperature on plants; thereby, help developing a micro-climate in surroundings that encourages plant growth.

c. Activity of pollinating insect will be enhanced.

d. They provide large quantity of biomass (leaves) for manuring and mulching.

e. They can provide fodder, firewood and small timber in limited quantities (Krishna *et al.,* 2013a).

Fig. 2a. A view of wind break in *ber* based cropping system.

Fig. 2b. A view of wind break in *aonla* based cropping system with *Cordia myxa.*

Characteristics of trees for windbreak

a. The trees should be tall growing and sturdy enough to withstand strong winds.

b. They should be profusely branching.

c. They should have high regenerating capacity, if they are pruned during non-windy season to have sufficient interlocking branches during windy season.

d. They should have minimum or no adverse effect from the wind on their growth and physiological functions (Saroj *et al.,* 2004).

Common trees to be used as wind breaks

Some of the most common trees, which are used as wind breaks are *Shisham* (*Dalbergia sissoo*), Mulberry (*Morus alba*), *Jamun* (*Syzygium cumini*), *Bordi* (*Zizyphus rotundifolia*), *Neem* (*Azadaricta indica*), *Lasoda* (*Cordia myxa*), *Babool* (*Acacia tortilis*), *Khejri* (*Prosopis cineraria*) *etc.* (Saroj *et al.,* 2004).

Shelter belt

Shelter belts are wide and long belts of several rows of shrubs planted across the prevailing wind direction to deflect wind currents to reduce wind velocity and provide general protection against sand movement of vast fields.

For an ideal shelter belt, one of the most important pre-requisite is a suitable arrangement of trees, shrubs and grasses on the windward side. The tall growing trees should be planted in the middle to ensure maximum height while those on either side should be short and of a more bushy variety to maintain a dense low barrier. Planting of, these should be staggered to provide compact barrier.

Characteristics of plants for shelterbelt

(a) The species should be fast- growing in nature.

(b) The species should have ability to withstand high wind velocity.

(c) The species should be long lived.

(d) The species should form a dense crown cover,

(e) The species should form litter in abundance on the plantation floor.

(f) The species should be resistant to abiotic stresses like drought and frost (Muthana, 1997).

Common trees to be used for shelter belt

Tree species such as *Acacia tortilis*, *Prosopis juliflora* (Israel variety), *Cassia siamea*, *Azadirachta indica*, *Albizzia lebbek*, *Acacia nilotica* spp. *Cupressiformis etc*. and shrubs like *phalsa*, *karonda, khimp* (*Leptodenia pyrotechnica*) or *phog* (*Calligonum polygonoides*) are suitable for the purpose of establishing shelter belt.

ii. Propagation and planting

In situ budding is of great importance to establish orchard under rainfed conditions especially, in arid areas. Establishment of orchard by this technique for resource poor farmers has been widely suggested. Since nursery propagated plants invariably lose their tap roots as a result of repeated transplanting or develop coiled roots when raised in pots or polybags, *in situ* budding is preferred. In *ber*, *bael*, *aonla*, as per the land suitability, seeds of desired species are sown during August-September at proper spacing in the field. The rootstock raised in this manner develop deep tap root system and hence they have more drought resistance. The seedlings are protected till next summer (when the rootstocks are 9-10 months old or in May-June) when they are headed back at ground level. The rootstock will give out new shoots during monsoon season and budding with suitable scion cultivar/variety is done when the shoots attain pencil size thickness.

For raising seedlings of vegetable crops as intercrops like *mateera*, improved method of seedling production such as plug tray production/pro-tray grown seedlings using coco peat, nylon net protection and bio-fertilizers/bio-pesticide inoculation at nursery stage has good potential for obtaining sturdy, uniform and healthy seedlings. These seedlings when transplanted in the main-field will establish better with less root damage and fare better in overcoming biotic and abiotic stresses particularly during water stress conditions (Birbal *et al*., 2016).

Nursery raising

For raising the rootstocks/ seedling progeny of fruit crops, the seeds are sown either in seed bed or polythene bags. Seeds are sown during monsoon (June-July) or in the beginning of spring (Feb-March). Generally *Citrus, bael, phalsa, lasoda* seeds are sown during June-July while that of *ber* and *aonla* during February-March. Seeds of some fruits (*Citrus*, *lasoda*, etc.) lose viability quickly, so these should be sown immediately after their extraction from the fruit. Under North Indian conditions, the seeds of different *Citrus* species are available during winter months. Germination of seeds is low due to the prevailing low temperature. Hence, use of alkathene tent on seed-beds during December-January has been found useful in increasing germination percentage and faster growth of the seedlings.

The seeds are usually sown at a depth 3-4 times of its size. Sowing may be a little deeper than in heavy soils. It is essential to maintain proper plant density in bed as crowding may result in weak and lanky seedlings. Watering, shading, or sun exposure, incidence of diseases and frost affect seed germination and subsequent seedling growth. Rootstock seedlings are usually kept in seed bed for 1-2 years.

When the seedlings attain good size, these are transplanted in the field keeping the sufficient soil around their roots. After transplanting, plants are firmly pressed, irrigated frequently and protected from sun scorch. A starter or booster solution containing mineral nutrients can be given. Hardening of seedlings before transplanting can be done by withholding irrigation so that reduced growth, thickening of cuticle, increased waxy coating on leaves and increased proportions of dry matter enables the plants to withstand desiccation and proper development of roots (Sharma and Srivastav, 2004).

Care and handling of seedlings

After germination, the seedlings must be gradually exposed to light and increasing temperature. Over watering should be avoided. The frequency and amount of irrigation should be increased with the growth and development of the seedlings. Protection of seedling from frost during winter and from hot desiccating winds during summer is necessary. Similarly, the seedlings at younger stage may be infested by some insect-pests and diseases and thus spray of seedlings with pesticides should be taken on priority.

Hardening of seedlings

The seedlings raised in the nursery are very delicate and they cannot withstand transplanting shock unless they are properly hardened before transfer in the permanent site. It can be achieved by withholding water supply and reducing temperature or by combination of both. Thus, the reduced growth rate enables the plants to withstand desiccation and helps in the proper development of roots. However, over hardening may be avoided as it may result in extremely stunted plants. Thus, hardening of the seedlings should be done gradually for streamlined growth reduction (Sharma and Srivastav, 2004).

Criteria for selection

1) Reduction in growth rate of the seedlings.
2) Thickening of the cuticle.
3) Increase in waxy coating on the leaves.
4) Enhancement in the dry matter content of the seedlings.
5) Reduced transpiration rate.
6) Increase in the sugars levels of the leaves.

Morphological and physiological changes as a result of hardening are essential to promote the seedlings to withstand the shock of transplanting, which would help in their better establishment in the field.

Planting of budded plants

The digging of pits for out planting the budded plants should be done in hot weather during May-June; the layout for planting is generally done on square system. In western Rajasthan, planting distance of 6x6 m has been recommended for most of the crops. After layout of the orchard, pits of 60x60x60 cm size are excavated and filled with a mixture of top soil, FYM (about 10-15 kg) along with 50g chlorpyriphos dust (4%) to guard against termites. Planting is done after one or two rainfall when soil is well settled. While planting, the polythene tube is carefully removed by cutting from one side without disturbing the earthen ball and root system. The soil around the plant needs to be pressed from all sides after planting and watered immediately. Subsequently irrigation at 4-5 days intervals required for the first two months (Krishna and Singh, 2012).

Usually, there is high rate of mortality of saplings after planting. The major reasons for failure of saplings during transplanting are:

1. Poor root development.
2. The roots of the seedlings are soft and succulent.
3. The plants are not watered adequately.
4. If the plants are not pressed firmly to avoid air pockets.
5. If the plants are not protected from scorching sun and wind by providing shade.
6. The environmental conditions existing in nursery bed are different to those in the field.

Plantation techniques for alkali soils

Planting technique for alkali soil involves digging pits of 1m^3. The pits are refilled with a mixture of 3 kg gypsum and 8 kg FYM before planting out 5 months old seedlings of selected species during rainy season A dose of 5 g zinc sulphate and 10 g Chlorpyriphos dust is also mixed in the filling mixture. Four irrigations are given after planting the seedlings at weekly intervals during first month. By this technique more than 80 per cent survival of seedling/saplings is obtained in highly alkaline soils (Birbal *et al*., 2016).

Plantation technique for saline soils

In saline soils, planting is done on the raised bunds. The width of bunds is 1 m at the base and 75 cm at the top. If the terrain is flat at the planting site, the site is ploughed two to three times using a tractor and then bunds are constructed. 1m^3 pits are dug out at the top of bunds in the centre; 4 kg of FYM is mixed in excavated soil for each pit before back-filling. If the salinity level is quite high the quantity of FYM is often doubled. Many a time good soil is brought from nearby areas for back-filling the pit for planting the seedlings. If better quality water is available, the plantations are irrigated as and when possible, at least for first three years, which is highly beneficial (Subbulakshmi *et al*., 2016).

iii. Enrichment of soil organic matter content

Constant efforts must be made to improve the soil organic carbon. Incorporation of crop residues which are free from allelopathic effect and farm yard manure to soil improves the organic matter status, improves soil structure and soil moisture storage capacity. Organic matter content of the soil can also be improved by following alley cropping, green manuring, crop rotation. Vegetables being short duration crop and having faster growth phases, the available organic matter needs to be properly composted. Vermi-composting can be followed for quicker usage of available organic matter in the soil and improving the soil moisture holding capacity.

The soil of the region is deficient in organic carbon and nitrogen. The farmers cannot afford costly fertilizers to supplement plant nutrients. Hence, they use organic manure mostly excreta of cattle and small ruminants to enrich soil fertility. Besides, providing adequate nutrients these manure helps to conserve moisture and augments productivity of vegetables in the region.

The indigenous plants which come with onset of rain is incorporated and some of species *i.e. Calligonum polygonoides* is reported to improve productivity of crops (Subbulakshmi *et al*., 2016).

iv. Application of foliar nutrition

The foliar application of nutrients during water stress conditions helps in better growth by quick absorption of nutrients. The spraying of K and Ca induces drought tolerance in vegetable crops. Spraying of micronutrients and secondary nutrients improves crop yield and quality.

v. Moisture saving methods

Under limited water situations, water-saving irrigation methods like alternate furrow irrigation or widely spaced furrow irrigation and micro-irrigation systems can be adopted. Studies conducted on methods of irrigation indicated that adopting alternate-furrow irrigation and widely-spaced furrow irrigation saved 35 to 40 per cent of irrigation water without adversely affecting yield.

Drip irrigation

Drip irrigation has proved its superiority over other conventional method of irrigation in horticulture due to precise and direct application of water in root zone. A considerable saving in water, increased growth, development and yield of fruits and vegetables and control of weeds, save in labour under drip irrigation are the added advantages. Drip irrigation can be adopted in fruit crops and also to all vegetable crops. The saving in water is to the tune of 30-50 % depending on the crop and season.

Micro-sprinkler irrigation

Depending upon situation and availability of water, this technology can be used for fruits and vegetable crops. The cost of initial establishment is lower compared to drip system. Further in summer the sprinkling of water helps in reducing the microclimate temperature and increasing the humidity, thereby improving the growth and yield of the crop. The water saved is to the tune of 20 to 30 per cent (Birbal *et al*., 2016).

Mulching

Any material used (spread) at surface or vertically in soil to assist soil and water

Benefits of mulching

1. Soil moisture conservation.
2. Suppression of weeds.
3. Reduction in soil erosion from wind or water
4. Protection of plant roots from extreme temperatures.
5. Promotion of growth of beneficial soil organisms.
6. Reduction in soil compaction caused by equipment and people.
7. Improvement of soil texture (in case of organic mulch).
8. Prevention of leaching of fertilizers.
9. Reduction in incidence of disease by protecting above-ground plant parts from splashes, which carry soil-borne inoculums.
10. Improved fruit productivity.

conservation and soil productivity is referred as mulch. Technically, the term 'mulch' denotes 'covering of soil'. Basically, there are two types of mulches (organic and inorganic) depending upon the materials used as mulching.

Organic mulch is made up of natural substance. The organic materials such as crop residues and by-products, farm yard manure and by-products of timber industry, when used for mulching, are known as organic mulches. Despite imparting nutrients to soil after their degradation apart from other benefits as listed here, the use of organic mulches should be done carefully in regions, where termite infestation is severe. However, care should be taken that organic muclches should not have allelopathic effects for example bulk of neem litter should not be used as organic mulch, which have strong allelopathic effects when incorporated near the planting site.

How to apply organic mulches?

- Prepare the soil by removing weeds, raking or digging the surface.
- Apply the mulch in a circle around the tree.
- Make sure the mulch measures about 2 to 3 inches in depth.
- Spread the mulch evenly around the tree by using soil rake well beyond its drip line (spread of the outer most branch of tree).
- Leave a space around plant stems; otherwise they may rot. The root flare, where the roots begin to enter the ground at the base of the trunk, should be visible after the mulch is spread.

Recently plastic mulches have come into use. Generally polyethylene mulch film of 30 micron thick and 1 to 1.2 m width is used. There are different types of plastic mulches tailor made for specific purposes. For instances, black plastic film does not allow the sunlight to pass through on to the soil. As a result, photosynthesis does not take place in the absence of sunlight below black film, which leads to suppression of weed growth. Besides, it helps in conserving soil moisture and reducing outgoing radiation, while clear or transparent mulches will allow sunlight to pass through and the weeds will grow. However, by using herbicide coating on the inner side of film weed growth can be checked. Since, it increases the soil temperature; therefore, it is preferably used for soil solarization. There are two-side colour mulches, which due to their reflection of different wavelengths of light create specific environments, which have a considerable effect on plant growth and development (Krishna *et al.,* 2013a). They are available in following colour combinations;

- Yellow/black: Attracts certain insects & thus acts as a trap for them, which prevents disease.
- White/black: Cools the soil.
- Silver/black: Cools the soil, though not to the extent of white/black film & repels some aphids & thrips.
- Red/black: Improvement of vegetative & floral growth of plants, early fruiting and increased yield.

Steps for laying plastic mulches

- Mulching area should preferably be equivalent to the canopy of the plant (larger the canopy, larger the area of mulching and *vice versa*).
- Required size of mulch film is cut from the mulch roll. Maintain equal length and breadth.
- Cut the film using a scissor from the middle from the middle of one side to the centre of the mulch film.
- Cut the film in star shape.
- Clean the required area by removing stones, pebbles, weeds etc. Till the soil well and apply a small quantity of water before mulching.
- If required, a small trench could be made around the periphery of the mulching area to facilitate anchoring of the mulch film. The borders (10 cm) should be anchored inside the soil in about 7-10 cm deep in small furrows at an angle of 45°.
- Open the film from the cut portion and insert the tree/plant in between the cut portion and cover the entire area.
- The mulch material should be held tight without any crease and laid on the soil.
- The cut portion of the film should be overlapped upto 6 inches and the overlapped end should be buried in the ground.
- The overlapped portion of the film could also be sealed using a plastic tape or by using metal hooks made out of 1mm binding wires.
- Semi circular holes could be made at the four corners of the film in order to facilitate water movement.
- The position of the slit or opening should be parallel to the wind direction. It should not be placed perpendicular to the wind direction as this could facilitate entry of air through the opening and result in tearing of mulch film.

vi. Canopy management

The main objective of canopy management is to give a suitable shape to the tree and to ensure regular yields to avoid over-bearing and to get high quality of fruits. Canopy management entails two principal practices *viz.*, training and pruning. Fruit trees require training during the initial few years of orchard establishment to give them proper shape and strong frame, while pruning is done during bearing age of the tree and continued until tree remains productive. The bushy pomegranate should be trained keeping 3-5 stems from the ground level. In other fruits, single stem training is done keeping properly spaced 3-4 main branches. Branching at desired heights can be induced by pruning. Annual pruning may be required in some species to obtain quality fruit production, e.g. in *ber*, *phalsa* and pomegranate, pruning time varies in different fruits. Annual pruning is done during summer in *ber*, in February in *phalsa*, and in early summer in mulberry. Defoliation is done in *goonda* during the winter to induce early flowering and fruiting. Lopping of *Prosopis* trees is done, traditionally, during November-December to obtain leaf fodder and fuel wood. Complete lopping gives higher yield of leaf fodder (58.7

kg/tree) than by lopping two-third (28.5 kg/tree) or one-third (19.7 kg/tree) crown. For the production of edible pods the trees are kept unlopped. However pruning during May-June, is advised to ensure pod production as well in pruned trees.

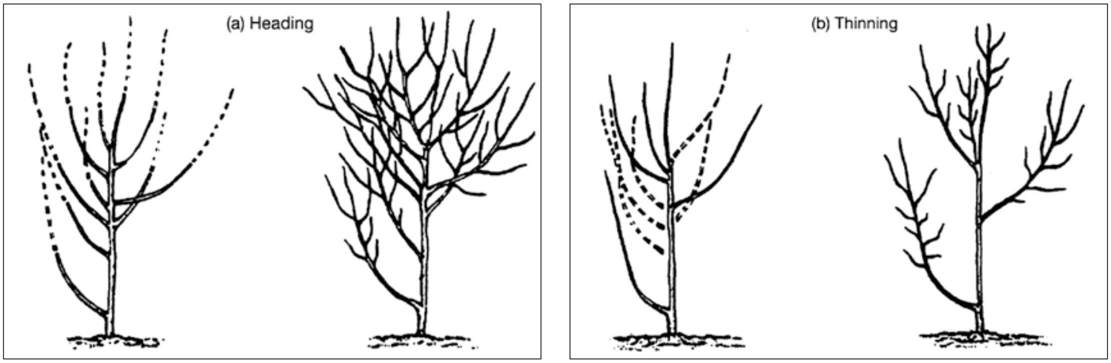

Fig. 3. Schematic representation of heading back and thing out.

While pruning several facts should be kept in mind as even a single cut may have its impact on bearing of fruiting trees. For instance, a tree's response to a pruning cut depends on where on the branch the cut is made. Two types of cuts are used in pruning fruit trees (Fig. 3). (i) Heading cuts: Several buds left on the cut branch grow, making denser, more compact foliage on more branches, (ii) Thinning cuts: Branches are removed entirely, leaving no buds to grow. Their energy is diverted into remaining branches, which grow more vigorously.

Similarly, angle of pruning cuts also influences branching behavior. It is desirable to always make cuts close to a node. Since, branches grow only at these nodes; therefore, if a too long a stub beyond such node is left, the stub will die and rot. Usually, a branch is prune to the lateral bud, which will produce the desirable subsequent branch. The placement of that bud on the stem points the direction of the new branch. An outside bud, pruned with a slanting cut just above the bud, will usually produce an outside branch. A flat cut above the bud encourages two lower lateral buds to release and grow shoots (Fig. 4).

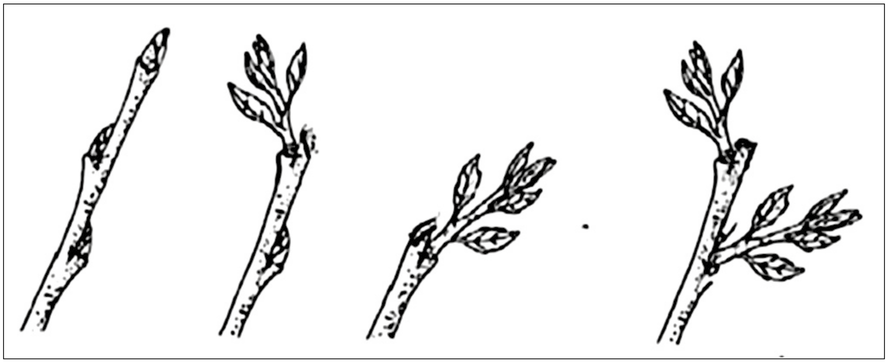

Fig. 4. Placement of pruning cuts.

It should always be kept in mind that for cutting small branches or limbs, cuts to remove limbs should be made as close as possible to the main trunk or subtending branch. There should be no stub or projecting end of the cut branch. Likewise, for cutting of thicker branches, preferably, use a pruning saw. Start cutting from underside of the branch and then cut through the rest from the top (Fig. 5). This stops the bark tearing away as the branch falls, leaving a wound, which can serve as a entry point for pathogen/disease. If the branch is heavy, it can be cut into several sections to ease some of the weight.

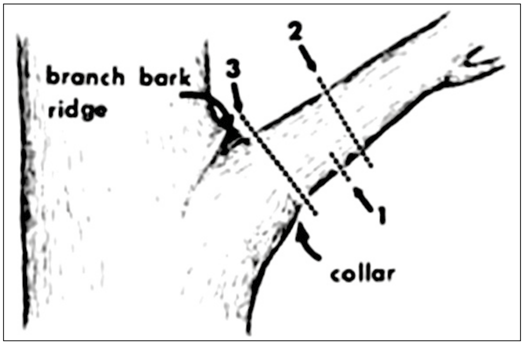

Fig. 5. Use a three-step pruning method on large limbs. 1) Undercut to prevent bark stripping. 2) Remove most of limb. 3) Remove stub, making cut outside of branch bark ridge and collar.

When to prune?

Pruning is done generally when plants are dormant and exhibit no signs of active growth. This is also termed as dormant pruning. However need-based pruning can be done year round, for example, dead or diseased branches can be removed any time, the sooner the better. Dormant pruning is excellent way to shape a young tree or reshape an older tree. In arid fruit like *ber,* dormant pruning is done during summer (May-June) as plants go into dormancy during hot months. Dormant pruning encourages the growth of vigorous new leafy wood. On the other hand, pruning done during active growth phase encourages the growth of less-vigorous fruiting wood, so it is the best time for trimming branches and renewing fruiting wood. Pruning during the post-dormancy and pre-dormancy is generally the least desirable time as the plant is most vulnerable during those times.

What to prune?

- In fruit trees, which bear fruits on previous seasons' growth, laterals are shortened (headed back) to encourage the development of fruit buds.
- Trees, which bear fruit on the current season's growth, require thinning out of some of the branches by cutting them right back to where they sprout from the branch or trunk.

Stage of pruning

Training of the young non-bearing trees

- Less pruning is done during this period so as to achieve more quick growth for tree to come into bearing.
- Consequently, once the main branches are selected, minimal pruning is done until the tree comes into bearing.
- Light pruning is followed in the third and fourth years, primarily by thinning-out instead of heading-back.

- Heading-back is, generally, avoided from the second year, until the trees are in heavy bearing.
- Branches, which form narrow crotches (less than 45 degrees) with the trunk, are removed.
- Similarly, branches, which grow straight up or into the tree, those which are weak and drooping, and those, which tend to cross or otherwise interfere with others are also eliminated.
- Strong crotch angle may also be developed by spreading the limbs to a more horizontal position.
- Usually, five-seven main branches are retained to build a good tree.
- Five to seven scaffolds should fill the circle of space around the trunk. This arrangement prevents one limb from overshadowing another, thereby, reducing competition for light and nutrients.

Pruning of the mature fruit trees

- Most pruning is done when the trees are dormant.
- In the orchard, pruning should be started early enough to be completed before the leaves appear.
- The risk of injury increases if pruning is begun too early.
- All pruning has a dwarfing effect, but dormant pruning produces the most new growth.
- The harder the cutting, the greater is the response in new shoot growth. The response takes place in the area of the tree where the cuts are made.

Training

Training is done to develop a tree framework strong enough to bear large fruit crops without the branches breaking. There are three main training systems: (a) central leader, (b) modified leader, and (c) open centre or vase system; however, in majority of the fruit crops modified leader is followed.

Modified leader

- This system is followed in arid fruit crops like *aonla*, *bael*, *karonda etc.* In fact, this system is suitable for managing the canopy of most of the arid fruits.
- The central leader is retained for a distance of about 1 to 2 m and then cut back to encourage laterals as is done in case of open centre trees.
- Laterals are selected in ascending order in a relatively spiral fashion up the central trunk, which are cut back until the proper number and distribution of branches have been attained.
- The lowest lateral remains 60 cm or more above the ground. When the central leader is removed, the tree develops a top that is round and open (Fig. 6).
- The limbs are low and well-spaced, and the fruiting wood is well- distributed. This facilitates many orchard operations.

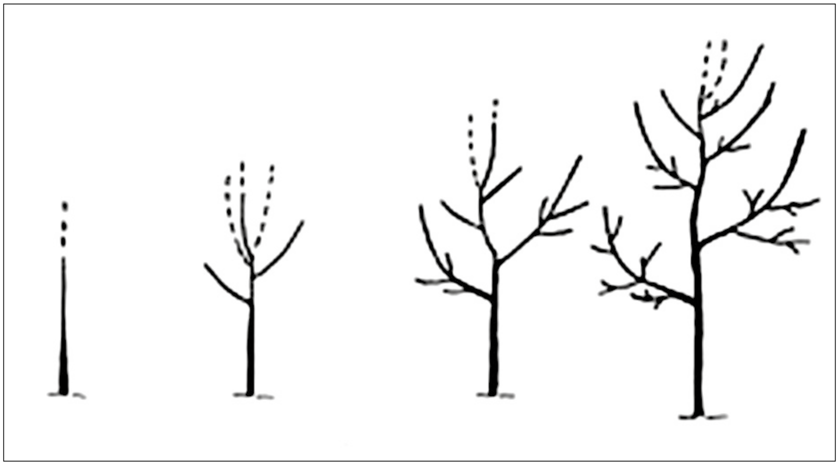

Fig. 6. Modified leader form during the first four years (left to right). Dotted lines represent portions of the tree, which should be removed by pruning during the dormancy.

Some points to remember

- Ensure that secateurs and loppers are sharp so they don't make jagged cuts or tear limbs/ branches.
- Between trees, blades of pruning equipment should be wiped with methylated spirit or alcohol to avoid dissemination of diseases from one to another tree.
- Dispose all the pruned material from the orchard. Immediately burn or bury the dead or diseased branches or mummified (brown and shriveled) fruits.
- After pruning, dress the wound with some fungicidal preparations such as Bordeux paste (Copper sulphate- 1000g + Lime- 1000g + Water- 10L; 1:1:10), Chaubattia paste (Copper corbonate- 800g + Red lead/ *Sindoor*- 800g + Linseed oil- 1L) or Mashobra paste (Stearic acid- 25.5g + Morpholine- 9cc + Tap water- 340cc + Lanoline- 136cc + non-sterile streptomycin- 3.1g).

Canopy management in *karonda*

Adoption of proper canopy management practices is said to be an important cultural practice for sustainable fruit production. In a study, *karonda*, under diversified fruit based cropping system, were pruned with different pruning intensities *viz*., mild pruning (involving thinning of criss-crossed and dried branches), medium pruning (by retaining 4-6 scaffold branches) and severe pruning (heading back at 45 cm height from ground) during the month of February-March (Fig. 7). Thinning of crowded shoots was performed in severely pruned plants in subsequent years. The unpruned plants yielded 7-9 kg fruits, while mild pruned plants recorded 10-12 kg fruits per tree in first year. However, medium pruned registered 12-14 kg fruits per tree. As a result of medium pruning, on one hand yield was increased, while on the other hand, the harvesting period was also hastened by about three weeks (first week of August) in comparison to mild pruned plants. In mild pruned plants, the harvesting period was fourth week of August. The severe pruned plants exhibited sparse flowering and bore only few fruits during first year, which could be attributed to drastic loss of carbohydrate reserve (stored in pruned branches) as a result of pruning (Krishna, 2012). Pruning might have helped restoring a balance between vegetative and reproductive growth, which otherwise was tilted towards vegetative growth. Though, *karonda* is a shrub like evergreen fruit crop; however, the findings of this study suggested that medium pruning could be an essential operation to strike a balance between vegetative and reproductive growth. Further, these findings necessitate the adoption of suitable pruning strategies for the regulation of yield and harvesting season, keeping in view the need of the growers, which is primarily market-driven.

Unpruned *karonda* plants in bearing.

Mild pruned *karonda* plants.

Medium pruned *karonda* plants

Severe pruned *karonda* with overcrowded branching.

Fig. 7. View of *karonda* plants pruned with different intensities .

7. Frost management

Plants grown in arid region encounter various stresses during their life cycle. Among various environmental stresses, cold or low temperature is one of the most important factors limiting the vegetative growth and fruiting. In recent years, there is a shift in the maximum and minimum temperature in arid region. Occurrence of low temperature/ frost has become a recurrent feature during winters and temperature even goes below 0°C in some districts of Rajasthan, causing huge economic losses if plants are in bearing stage. Due to frost, the developing fruits may 'mummified'. In severely affected plants, the foliage exhibits a typical 'frost burn' appearance. This usually occurs when thawing of ice crystals formed in intercellular spaces is slow and as a result the cells are deprived of water and become dehydrated; thereby, giving the 'frost burn' appearance.

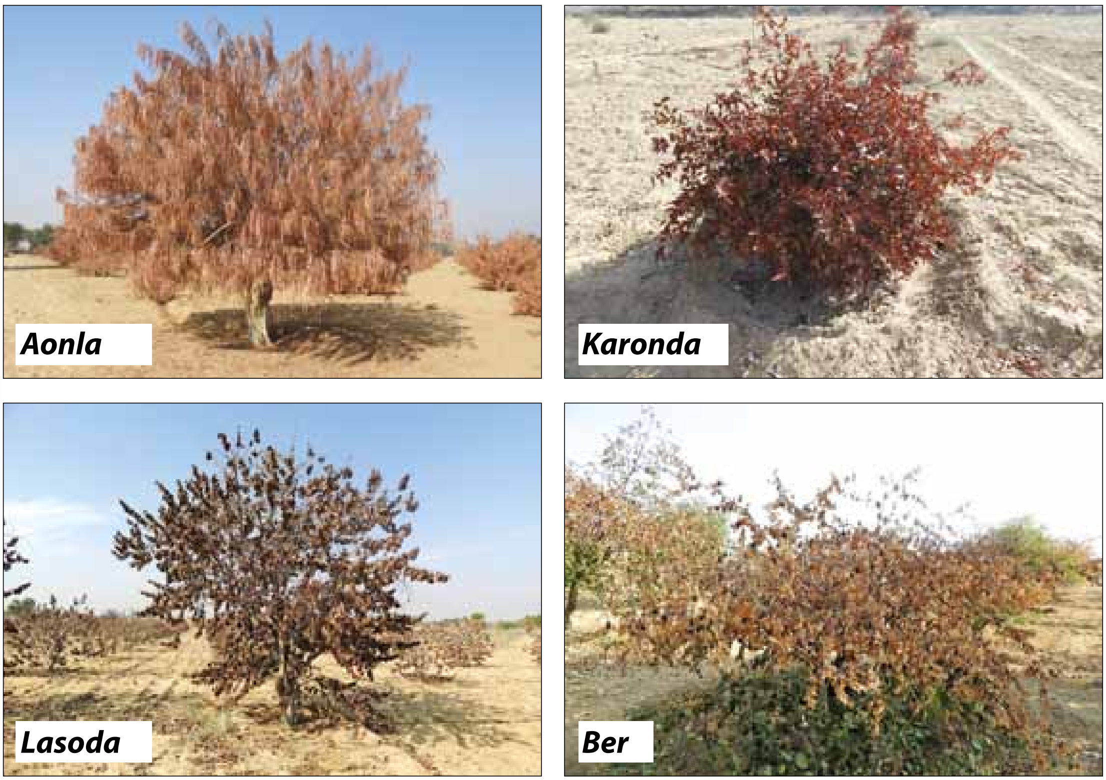

Fig. 8. Frost injury with typical 'frost burn' symptoms in different arid fruits.

Following management measures can be taken in advance of frost occurrence;

1. Since, the major site of frost perception is leaves, therefore defoliation of leaves before the onset of frost could be a suitable strategy to overcome this abiotic stress e.g. sprays of KI @ 1.5% or ethrel @1.5% in *aonla* and *lasoda* for induction of foliar abscission.
2. Spray of sulphuric acid @0.1% to plants is generally recommended as prophylactic measure.

3. Flood irrigation whenever, night temperature is expected to be low and sky is clear.
4. Generating smoke to reduce the damage caused by frost. This raises the temperature of nearby area by a few degrees and saves the fruit plant saplings from cold injury.
5. Thatching by local plant materials like *bui* grass, *bajra* straw, date palm leaves *etc*. to young saplings and keeping the south –east side open to let the sun in during winter.

Remedial measures to revive the damaged plants

Following remedial measures should be adopted to revive the plants from the injury;

1. Light irrigation should be given.
2. Light pruning of damaged plant parts/ shoots should be done followed by spraying of fungicides.
3. Manuring/ Fertilizer application should be undertaken as soon as the minimum temperature rise up to 15^{0}C along with light irrigation for speedy recovery of plants (Bhargava *et al*., 2014).

8. Management of fruit cracking in *bael*

Fruit cracking is one of the major production problems in *bael* (*Aegle marmelos* Correa.) cultivation under arid environment. Average losses due to fruit cracking could be up to 50% depending upon the prevailing environmental conditions. In general, cracking occurs as a result of excessive water absorption by fruits or sudden changes in atmospheric temperature. Within the fruit, the mesocarp expands but epicarp is unable to do so and as a result cracking happens.

In order to prevent the fruit cracking, the necessity was felt to provide external mechanical support to epicarp. 'Cling film' a plastic packaging, is a very thin polyethylene film, which upon wrapping around fruits adheres to the surface of fruit and serves as an extra covering. The wrapping of fruits with cling film results in reduced fruit cracking. (Fig. 9). Another, interesting observation was effect of hail on fruit cracking of *bael.* Occurrence of heavy hail storm results in unprecedented fruit cracking in *bael* due to abrupt fluctuation in temperature and RH (Fig. 10). Cling film wrapping results in less cracking of *bael* fruits, despite hail storm. Sixty per cent fruits can be saved due to wrapping with cling film, while cracking was noted to the extent of 95% in control fruits. Besides, severity of cracking on individual fruits was more intense (multiple cracking with wider and deeper cracks) in unwrapped control fruits (Fig. 10). Reduced fruit cracking in wrapped fruits could be attributed to external mechanical strength provided by cling film to epicarp (Krishna *et al.*, 2016).

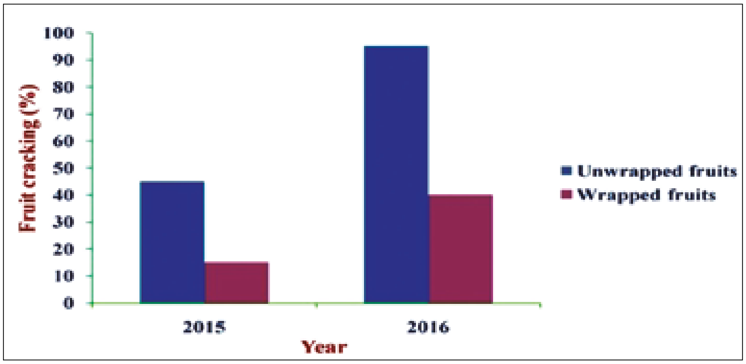

Fig. 9. Severity of fruit cracking in bael.

Fig. 10. Fruit cracking in wrapped and unwrapped bael fruits post hail storm in 2016.

Besides reduced fruit cracking, individual wrapping have several other merits over unwrapped control fruits such as reduction of decay from secondary infection, delayed senescence and improved shelf life. Wrapped fruit could be stored for 03 months after harvest (*i.e.* till 3rd week July) under ambient conditions in comparison to unwrapped control fruits, which are consumed within 7-10 days of usual harvest made during mid April. Use of cling film improved appearance as they develop uniform attractive colour within 5-7 days after removal of cling film at ambient conditions (Fig. 11). In addition, wrapped fruits also registered higher antioxidant contents (Table 6).

Fig. 11. Attractive rind and pulp colour development on fruits after removal of cling film.

Table 6. Phytochemical constituents and antioxidant activities of *bael* fruits.

S. No.	Attributes	Wrapped fruits	Unwrapped control fruits
1	Soluble solids content (^{0}Brix)	33.16a*	33.79a
2	Acidity (%)	0.11b	0.15a
3	Ascorbic acid (mg/100g)	14.38a	12.46b
4	Carotene (IU)	1238.27a	1095.59b
5	Total phenolics (mg/g FW)	19.26a	15.74b
6	Flavonal (mg/g FW)	3.18a	2.39b
7	Total flavonoids (mg/g FW)	15.37a	12.61b
8	*O*-dihydric phenols (mg/g FW)	0.31a	0.23a
9	Total antioxidant activities (CUPRAC; µM TE/g)	98.07a	91.38b
10	Total antioxidant activities (FRAP; µM TE/g)	85.61a	81.53b

** Row values followed by the same letter are not significantly different.*

9. Cropping system models

a. *Aonla*-based system

Aonla is one of the important fruit crops of arid region. However, despite its adaptability in arid climate, productivity and economic return of the crop are affected by low temperature (-2°C) and frost (CIAH, 2006) which cause economic loss to the growers. In order to mitigate the risk of total crop failure, suitable multistorey crop combinations were evaluated at ICAR-Central Institute for Arid Horticulture during 2004-2008 in the inter-space of *aonla* orchard which could generate extra income, improve productivity, ameliorate and improve ecological situations (Awasthi *et al*., 2005; 2009). Mothbean grown during *kharif* season was a common ground storey crop grown in rotation with *rabi* crops i.e., fenugreek, chick pea, mustard and cumin. Growth parameters in terms of plant height, stem girth, canopy spread and canopy volume of *aonla* was recorded to be significantly more with intercrops compared with its sole plantation. Higher grain and straw yield were recorded in moth bean-chickpea (497, 1250 kg/ha) and moth bean-fenugreek (465, 1161 kg/ha) crop sequence. Amongst the *rabi* crops, grain yield of fenugreek, chickpea, mustard and cumin were higher by 28.05, 38.11, 19.96 and 36.05%, respectively, when grown in association with *aonla* compared to its sole crops. The highest net profit (28260/ha) was obtained from moth bean-cumin cropping system, followed by moth bean-chickpea (25024/ha) cropping system. Moth bean-chickpea intercropping with *aonla* supplemented 22.01, 5.00 and 27.90 kg/ha nitrogen, phosphorus and potassium through crop residues, followed by moth bean-fenugreek crop sequence.

Arya *et al*. (2010) compared the fruit based multispecies cropping systems versus sole cropping system under arid regions of Rajasthan by comparing 4 multi-species cropping models and sole of each crop involving 11 treatments. The ground storey crops namely, cluster bean and moth bean were raised during rainy (*kharif*) season, while mustard and brinjal were raised during winter (*rabi*) season. Significant differences were recorded in yield levels of perennial as well as ground storey components in multispecies cropping models [I. *aonla* (*Emblica officinalis*) + *ber* (*Ziziphus mauritiana*) + *karonda* (*Carissa carandas*) + cluster bean (*Trigonella foenum graecum*) + brinjal (*Solanum melongena*); II. *aonla* + *ber* + *karonda* + cluster bean + fallow; III. *aonla* + *ber* + *karonda*+moth bean + mustard; IV. aonla + *ber* + *karonda* + moth bean + fallow] as compared to sole cropping [V. *aonla*; VI. *ber*; and VII. *karonda*]. The growth and yield in perennial component were more under the multi-species cropping systems, *i.e. aonla* (*Emblica officinalis*) + *ber* (*Ziziphus mauritiana*) + *karonda* (*Carissa carandas*) + cluster bean (*Trigonella foenum graecum*) + brinjal (*Solanum melongena*) and *aonla* + *ber* + *karonda* + cluster bean + fallow. Minimum yield was recorded in sole perennial crops. Plant height, number of branches/plant, pods/silique/fruits/plant and yield was found to be superior in multi-species cropping systems of *aonla* + *ber* + *karonda* + cluster bean + brinjal and *aonla* + *ber* + *karonda* + mothbean [*Vigna acontifolia* Jacq. Marechal] + Indian mustard (*Brassica juncea* (L) Czernj & Cosson] as compared to sole cropping, except mustard where a reverse trend was observed. As compared to its sole crop, fruit yield in *aonla* increased by 220.84% in model III to 208% in model IV. Similar yield trend was observed in case of *ber,* where it was higher by 53.64% in model III. Fruit yield in *karonda* increased by 124.48% in model II to 121.93% in model III. In rest of the multi-species cropping models, a general increase of 50% was recorded. Improved growth and yield of perennial fruits under multi-species cropping could be due to addition of leaf biomass to the soil and their further decomposition in the soil as a mulch via conserving moisture, thereby, favouring source-sink relationship, which in turn resulted in higher fruit yield under multi-storey cropping system. Positive influence of intercrops on growth and yield of perennial species have been established by various workers (Awasthi *et al*., 2009; Saroj *et al*., 2003; Saroj, 2004).

Impact of canopy on over, under and ground storey crops

The yield parameters *viz*., number of pods/silique/fruits/plant and yield/ha of ground storey crops were significantly higher in multi-species crop combinations, except mustard which produced 450.2 silique/plant in cropping model III with *ber* as against 467.5 silique/plant in sole cropping. When it was translated into yield, it resulted into higher yield of mustard when grown as sole crop (1.50 tonnes/ha) as compared to multi-species cropping model (1.40 tonnes/ha). Allelo-chemicals released by *ber* and *aonla* leaves may also be attributed behind reduced plant height and yield in mustard. Saroj *et al.* (2002) and Awasthi *et al.* (2005) reported the effect of allelo-chemicals on mustard crop treated with aqueous leaf extracts of *ber* and *aonla*, respectively.

Cash-flow and economic analyses

Later, the cost of cultivation, gross return and net income per hectare were worked out by Arya *et al.* (2011) for different multi-species cropping models including sole of each crop, which is presented in Table 7. Similarly, the cash-flow of the system has also been presented in Fig. 12. Cost of cultivation in perennial sole fruit crops varied between Rs. 8,000 for *karonda* to Rs. 15,200 for *ber*, while in seasonal ground storey crops, it varied between Rs 4,100 in moth bean to Rs. 34,656 in brinjal. In multi-species cropping models-II and model-IV, an average net return of Rs. 67,000 was recorded. Among the sole crops, maximum net return was realized from *ber* (Rs.18, 596) followed by mustard (Rs.13, 827) and *karonda* (Rs. 7,750), while the minimum net return was recorded from brinjal (Rs. 1,644). Net return in *aonla* was worked out as negative *i.e.* –Rs.7, 934 due to frost damage during the period of investigation.

In another study, Newaj and Rai (2005) analyzed 13 years of an *aonla*-based agroforestry system in marginal lands under rainfed conditions and found a B:C ratio of 3.28 (on a discounted rate, 2.61) which indicated its profitability. Similarly, there are studies indicating profitability of the system. A comprehensive analysis indicated their economic viability, with an IRR ranging from 25 to 68 and a B:C ratio of 1.01 to 4.17 for 24 agroforestry systems in various agro-climatic regions of the country (Planning Commission, 2001).

Fig. 12. Cash flow from *aonla* based cropping system.

Table 7. Cost and return per hectare of mixed multi species cropping models v/s sole cropping.

Cropping models	Gross return (D)	Cost of cultivation (D)	Net return (D)	Cost: benefit
Aonla+ber+karonda + cluster bean + brinjal (I)	150954.7	48750	102204.7	3.14
Aonla+ber+karonda +cluster bean+ fallow (II)	101492.5	33750	67742.7	3.07
Aonla+ber+karonda + moth bean+ mustard (III)	122011.8	37362	84650.3	3.48
Aonla+ber+karonda +moth bean + fallow (IV)	100393.1	33250	67142.5	3.09
Aonla (sole) (V)	2065.8	10000	-7934	0.20
Ber (sole) (V)	33796.8	15200	18596.8	2.22
Karonda (sole) (VI)	15750	8000	7750	1.96
Cluster bean (sole) (VII)	8124	6000	2124	1.35
Moth bean (sole) (VIII)	6660	4100	2560	1.62
Brinjal (sole) (IX)	36300	34656	1644	1.04
Mustard (sole) (X)	21240	7413	13827	2.86
SEm±	857.33	-	813.54	0.16
C.D. (5%)	2476.14	-	2349.68	0.47

b. Fruit based seed spice diversified cropping models

The demand for seed spices is predicted to be three fold of the current consumption by 2050 in the country (Malhotra and Vijay, 2000). Integration of seed spices with fruit trees is necessary for increasing system productivity and income of farmers (Anwar *et al*., 2011). Intercropping of seed spices with fruit trees helps minimizing production related risks in event of adverse climatic condition (Vashishtha *et al*., 2005 and Mehta *et al*., 2007). Most of the seed spice crops are grown in arid regions (Mehta and Malhotra, 2007). In seed spice growing regions, major fruits are *ber* and *aonla*; therefore, it is advisable to integrate the production of arid fruit crops with different cropping sequences in order to ensure round the year on farm income.

A field experiment was conducted by Meena *et al*. (2017) with 20 treatments comprising six cropping sequences *viz*., nigella-cowpea, anise-cluster bean, rai-black gram, ajwain-tinda, fenugreek-okra, coriander -green gram undertaken with *ber* and *aonla*. The results revealed that all the cropping sequences intercropped with *ber* exhibited higher coriander equivalent yield over the cropping sequence intercropped with *aonla* (Table 8). They attributed the higher coriander equivalent yield with *ber* and *aonla* to additional yield of fruit trees which fetches good remuneration. Further, higher coriander equivalent yield of all the cropping sequence with *ber* was on account of higher fruit yield and better commodity price as compared to *aonla*. The highest coriander equivalent of 6549 kg ha^{-1} exhibited by fenugreek-okra cropping sequence intercropped with *ber* followed by nigella-cowpea cropping sequence (5825 kg ha^{-1}) intercropped with *ber*. The highest coriander equivalent yield of fenugreek- okra with *ber* might be due to favourable micro agro-climatic conditions available with *ber* which resulted higher grain production of fenugreek in this study.

Table 8. Effect of seed spice based inter cropping with fruit trees on yield of crops and fruits.

Treatments	Fruit yield (kg ha^{-1})	Yield of *rabi* crops (kg ha^{-1})	Yield of *kharif* crops (kg ha^{-1})	Coriander equivalent yield (kg ha^{-1})
Ber +Nigella+ Cowpea	25236	499	8400	5825
Ber +Anise+ Cluster bean	25227	523	5220	5319
Ber +*Rai*+ Black gram	25372	966	525	4831
Ber +*Ajwain*+ *Tinda*	24861	559	9500	5969
Ber +Fenugreek+ Okra	26271	1225	12600	6549
Ber + Coriander+ Green gram	25256	528	620	5027
Aonla +Nigella + Cowpea	48473	484	8200	4809
Aonla +Anise + Cluster bean	47246	514	5180	4252
Aonla +*Rai* + Black gram	46900	967	520	3726
Aonla + *Ajwain* +*Tinda*	47478	564	9180	4953

Treatments	Fruit yield (kg ha^{-1})	Yield of *rabi* crops (kg ha^{-1})	Yield of *kharif* crops (kg ha^{-1})	Coriander equivalent yield (kg ha^{-1})
Aonla +Fenugreek+ Okra	48358	1220	12400	5365
Aonla + Coriander + Green gram	47410	512	610	3957
Ber	24580	-	-	4097
Aonla	48425	-	-	3228
Nigella+ Cowpea	-	600	8950	1793
Anise+ Cluster bean	-	831	5460	1393
Rai + Black gram	-	1980	630	996
Ajwain +Tinda	-	800	9700	2093
Fenugreek + Okra	-	1250	11800	2073
Coriander + Green gram	-	832	760	1187
CD (p=0.05)	3818.94	98.65	882.42	451.63

* *Adopted from Meena et al. (2017).*

Cash-flow and economic analyses

The cash-flow of the above cropping system is being presented in Fig. 13. The economic analyses of different cropping systems showed that the gross return, net return and benefit cost ratio (BCR) were influenced with different cropping sequences. All the cropping sequences noted higher economic return when intercropped with *ber* followed by with *aonla* (Table 9). Higher return of all cropping sequences with *ber* was due to heavy fruiting and good market prices. In *aonla*, fruit yield was satisfactory but prices were comparatively low. Among all the cropping sequences, fenugreek-okra sequence was superior with both *ber* as well as *aonla* and the highest gross return (982275), net return (809215) and BCR (4.68) were recorded in fenugreek-okra cropping sequence with *ber* followed by nigella-cowpea cropping sequence with *ber* wherein gross return and net return were Rs. 873750/ha and Rs 705450/- ha^{-1}, respectively.

Fig. 13. Cash flow of cropping model.

The cropping sequence fenugreek- okra intercropped with *ber* exhibited highest coriander equivalent yield (6549 kg ha^{-1}), net return (Rs 809215/- ha^{-1}) and BCR (4.68) followed by intercropping of ajwain- tinda cropping sequence with *ber* which resulted a net return of Rs.722075/- ha^{-1}. Therefore, the intercropping of fenugreek-okra cropping sequence with *ber* was recommended for realizing higher system productivity, net returns and BCR.

Table 9. Effect of seed spice based inter cropping with fruit trees on net return and benefit fruits Cost of cultivation and BCR.

Treatments	Cost of cultivation (D)	Gross returns (D)	Net returns (D)	BCR
Ber +Nigella+ Cowpea	168300	873750	705450	4.19
Ber +Anise+ Cluster bean	159432	797835	638403	4.00
Ber +*Rai*+ Black gram	151800	724600	572800	3.77
Ber +*Ajwain*+ *Tinda*	173300	895375	722075	4.17
Ber +Fenugreek+ Okra	173060	982275	809215	4.68
Ber + Coriander+ Green gram	156060	754000	597940	3.83
Aonla +Nigella + Cowpea	173000	721330	548330	3.17
Aonla +Anise + Cluster bean	164132	637740	473608	2.89
Aonla +*Rai* + Black gram	156500	558950	402450	2.57
Aonla + *Ajwain* +*Tinda*	178000	742980	564980	3.17
Aonla +Fenugreek+ Okra	177760	804780	627020	3.53
Aonla + Coriander + Green gram	160760	593600	432840	2.69
Ber	110300	614500	504200	4.57
Aonla	115000	484250	369250	3.21
Nigella+ Cowpea	58000	269000	211000	3.64
Anise+ Cluster bean	49132	208920	159788	3.25
Rai + Black gram	41500	149400	107900	2.60
Ajwain +*Tinda*	63000	314000	251000	3.98
Fenugreek + Okra	62760	311000	248240	3.96
Coriander + Green gram	45760	178000	132240	2.89
CD (p=0.05)	-	67762.59	53620.43	0.18

** Adopted from Meena et al. (2017).*

c. *Aonla*-based horti-pastoral system

Farmers in arid regions are predominantly small, marginal and are resource poor. Livestock rearing, which provides nutrition and helps in stabilizing the farm income, is a complementary occupation in these regions. The combined pressure of human and livestock coupled with land degradation has resulted in shortage of green and dry fodder resulting in poor livestock productivity. On the other hand, horti-pastoral system has the potential to mitigate the shortage of dry and green fodder for feeding the fast increasing population of

livestock as well as nutritive food (fruit) to the human. *Aonla*-based horti-pastoral system involving *Dichanthium annulatum* grass as understory forage species was studied for ten consecutive years (1996-2005) by Kumar *et al*. (2009). Results showed that the pasture production was higher in association with trees (3.38 t DM ha-*1*) as compared to pure pasture (3.07 t DM ha-*1*). The mean B:C ratio over ten year of experiment was 1:1.85 for pure pasture and 1:3.70 for horti-pastoral system. The employment generation was 2.07-man-days month^{-1} in pure pasture and 4.74-man-days month^{-1} with incorporation- of *aonla* tree with the same pasture.

d. Fruit based diversified cropping system models: experiences at ICAR-CIAH, Bikaner

With a view to develop a cropping system, which have potential advantages in production, stability of output and ecological sustainability, evaluation of fruit based diversified cropping models integrating alternative crop components as under-storey fruit crop and ground-storey agricultural/spice and fodder crop was made at ICAR-CIAH, Bikaner.

The cropping system has *aonla* (*Emblica officinalis*) as base crop, while perennial crops like *ber* (*Ziziphus mauritiana*), *bael* (*Aegle marmelos*), *khejri* (*Prosopis cineraria*), drumstick (*Moringa oleifrea*), *karonda* (*Carissa carandus*) and fodder crop, sewan grass (*Lasiurus sindicus*) were taken as component crop. The interspaces of orchards were used to grow cluster bean and seed spices in *kharif* and *rabi* seasons, respectively in order to generate extra income, improve productivity, and ameliorate ecological situation in a sustainable manner. The system comprised of different cropping models such as *aonla-ber*-cluster bean-fennel, *aonla-bael*-cluster bean-coriander, *aonla-khejri*-cluster bean-*ajwain*, *aonla*-drumstick-cluster bean-dill and *aonla-khejri*-sewan grass. Different cropping models *viz*., *Aonla-Ber*-Cluster bean-Fennel (M-1), *Aonla-Bael*-Cluster bean-Coriander (M-2), *Aonla-Khejri*-Cluster bean-Ajwain (M-3), *Aonla*-Drumstick-Cluster bean-Dill (M-4), *Aonla-Khejri*-Grass (*L. sindicus*) (M-5) were assessed at ICAR-CIAH, Bikaner (Krishna *et al.,* 2013b).

Fruiting in *aonla* in *aonla-ber*-Cluster bean-Fennel (M-1) cropping model.

Bearing in *ber* in *aonla-ber*-Cluster bean-Fennel (M-1) cropping model.

Bearing in *khejri* in *aonla-khejri*-Cluster bean-*Ajwain* (M-3) cropping model.

A large size *bael* fruit harvested from *Aonla-Bael*-Cluster bean-Coriander (M-2).

Quality *karonda* in fruiting under diversified cropping system

Flowering and fruiting in moringa in *Aonla*-Drumstick-Cluster bean-Dill (M-4) model.

Intercropping with cluster bean.

Intercropping with seasonal vegetables and seed spices.

i. Yield

The average yield of *aonla* varied considerably in different cropping model systems after nine years with highest being recorded in *aonla-khejri* (46.2 kg per plant), *aonla-ber* (44.7) followed by *aonla-bael* (43.4 kg/plant) and *aonla-karonda* (42.5), while the lowest was recorded in *aonla-Moringa* (40.6 kg/plant). The higher yield in *aonla* involving *ber* and *khejri* could be due to synergistic crop interaction. The average yield of *bael* was recorded to be 20-25 kg per tree, while a single fruit weighed around 1.36 kg with maximum and minimum fruit weights recorded to be 2.7 kg and 0.7 kg, respectively. The average yield of *karonda* was recorded up to 13.4 kg/plant planted in between *aonla* plants. Likewise, the yield of *ber* cv. Seb was recorded to be 50.6 kg/ plant in model M-1 (Table 10). The improved growth of *aonla* under multiple cropping systems is likely to manifest itself in realization of higher yield (Krishna *et al*., 2013b).

Table 10. Average yield of over-storey and ground-storey crops in fruit based cropping system.

S. No.	Fruit crops	Sole crop (t/ha)	Multi-species (t/ha)
Over-storey perennial crops			
1	*Aonla*	6.8	7.4
2	*Ber*	7.9	9.5
3	*Bael*	1.6	1.9
4	*Khejri*	0.3	0.6
5	Drumstick	7.6	8.3
6	*Karonda*	6.1	9.4
Ground-storey crops			
1	Fennel	1.4	1.5
2	Coriander	1.4	1.7
3	*Ajwain*	3.3	3.8
4	Dill	2.6	2.9
5	Mustard	5.8	7.1
6	Cluster bean	6.0	6.2
7	*Sewan* Grass	-	15.7

ii. Soil nutrient status

Enhancing the long-term sustainability in productivity of crops and cropping systems is directly related to maintenance of an adequate level of soil organic matter. The benefits of maintaining desired levels of OC in low input agro-ecosystem are many like retention and storage of nutrient, increase in buffering capacity of soil, improvement in moisture retention and increased cation exchange capacity. Other benefits are activation of inherent microorganisms in rhizosphere. These aforementioned attributes consequently leads towards improved soil health and; thereby,

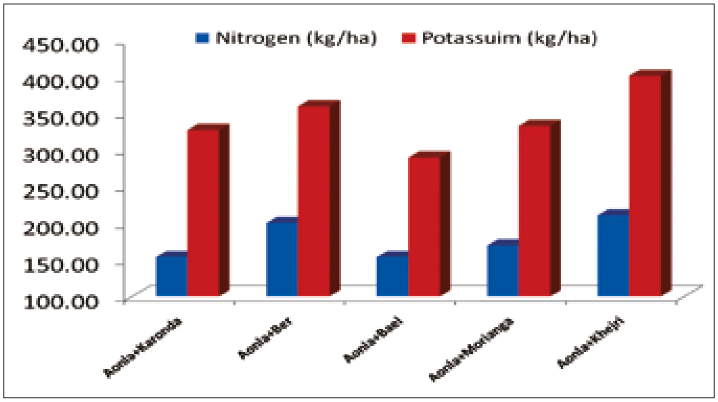

Fig. 14. Soil nitrogen and potassium as influenced by different cropping combinations.

bring sustainability in production system. Fruit trees contribute increase in organic carbon content in the soil due to decomposition of fallen leaves from them.

A comparative study of the soil properties over the initial values (2004) and 12 years after the establishment of cropping models showed considerable improvement in the soil organic carbon (OC), electrical conductivity (EC) and pH under *Aonla-Khejri*-Cluster bean-*Ajwain* cropping model followed by *Aonla-Ber*-Cluster bean-Fennel (0.25, 2.00 and 8.20, respectively) followed by *Aonla-Ber*-Cluster bean-Fennel (0.23, 1.61 and 8.26, respectively) (Table 11). Similarly, the maximum yield of nitrogen (kg/ha), potassium (kg/ha) (Fig. 14) and micronutrients (Zn, Cu, Fe and Mn ppm) was under *Aonla-Khejri*-Cluster bean-*Ajwain* cropping model (which was 210.30, 401.26 & 5.11, 0.59, 12.21, 12.91, respectively) followed by *Aonla-Ber*-Cluster bean-Fennel (200.20, 359.59 & 4.01, 0.45, 12.01, 12.76, respectively) (Table 11) (Jatav *et al*., 2016).

Table 11. Soil properties and micronutrient contents in different fruit based cropping system.

	OC	EC	pH	Zn	Cu	Fe	Mn
Initial status	0.02	1.00	7.81	0.41	0.25	5.75	6.00
Ber-Karonda	0.08	1.82	8.18	0.87	0.35	7.28	9.97
Aonla-Karonda	0.13	1.74	8.22	1.83	0.39	10.16	9.73
Ber-Aonla	0.23	1.61	8.26	4.01	0.45	12.01	12.76
Aonla-Bael	0.24	1.94	8.27	2.18	0.32	7.44	10.03
Aonla-Morianga	0.09	1.47	8.22	1.09	0.35	8.66	10.68
Karonda-Sewan	0.05	1.48	8.50	1.10	0.31	8.65	8.04
Aonla-Khejri	0.25	2.00	8.20	5.11	0.59	12.21	12.91
Minimum	0.05	1.47	8.18	0.87	0.31	7.28	8.04
Maximum	0.25	2.00	8.50	5.11	0.59	12.21	12.91
Average	0.15	1.72	8.26	2.31	0.40	9.49	10.59

iii. Nutrient supplementation through biomass

An integrated approach involving fertilizer nitrogen, crop residues, legume based cropping systems has been found to be useful for maintaining the soil fertility. Cluster bean grown in the inter-space of fruit trees played a vital role in supplementing N, P and K through the residues incorporated in soil. The beneficial effect of clusterbean is due to heavy leaf sheding (15.60 q/ha) and add as much as 10 - 12 kg N, 0.6 – 1.0 kg P and 25 to 40 kg K /ha/per season. The straw yield obtained from the cultivation clusterbean was to the tune of 31.0 q/ha. And it was estimated that the incorporation of this much straw added 22 kg/ha N, 1.86 kg/ha P and 77.5 kg/ha K to the soil mass (Jatav *et al*., 2016).

iv. Soil moisture status

Soil management practices that increase the soil water holding capacity (*via* improving the OM content in soil) and improve the ability of roots to extract more water from the soil profile, or decrease leaching losses could all potentially have positive impacts on water use efficiency (WUE), assuming these changes result in a concurrent increase in crop growth and yield. In case of annual crops, 74% of roots do not go beyond 50 cm soil depth, whereas, in case of perennial crops, top 50 cm almost devoid of feeder roots. The spatially differential root distribution of different component crops in the system helps in higher nutrient and WUE of the multitier system as a whole as a result of presence of feeder roots of the component crops at different depths. In the present investigation, Maximum water holding capacity at 0.33 and 6% bar was observed under *Aonla+Ber* (2.28 and 1.10%) followed by *Aonla+Khejri* (2.07 and 1.03%), *Aonla+Bael* (2.44 and 0.99%), *Aonla+Karonda* (1.76 and 0.61%) and *Aonla+Morianga* (1.84 and 0.56%) (Fig. 15 & 16). Water holding capacity of any soil is directly influenced by its organic carbon contents, which is also evident in this study wherein, *Aonla+Khejri* showed maximum accumulation of soil organic carbon as well as water holding capacity (Jatav *et al*., 2016).

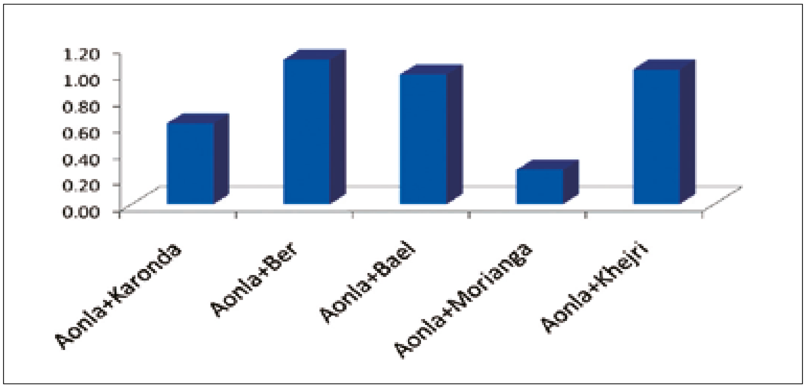

Fig. 15. Effect of *aonla* based cropping model systems on available moisture (%) at 6 bar in soil.

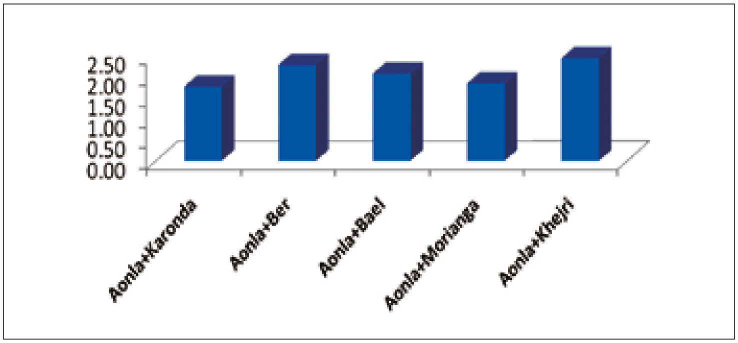

Fig. 16. Effect of *aonla* based cropping model systems on available moisture (%) at 0.33 bar in soil.

v. Soil microbial population

Plant species diversity in ecosystem encourages accumulation of organic material in soil, which in turn increases the general level of microbial activity in soil. In this respect, rotating a variety of crops provides ecological niches for microorganisms and encourages microbial diversity. Microbial count in the rhizosphere soil of crops in different treatment combination clearly indicates higher bacterial, fungal and actinomycetes population (271 cfux10^6, 221 cfux10^3 and 116 cfux10^3) in *Aonla+Khejri* followed by *Aonla+Ber* (205 cfux10^6, 164 cfux10^3 and 105 cfux10^3), *Aonla+Bael*, *Aonla+Karonda* and *Aonla+Moringa* (Fig. 17). The rhizo-deposition of nutrients by plant roots supports increased microbial growth (Jatav *et al*., 2016).

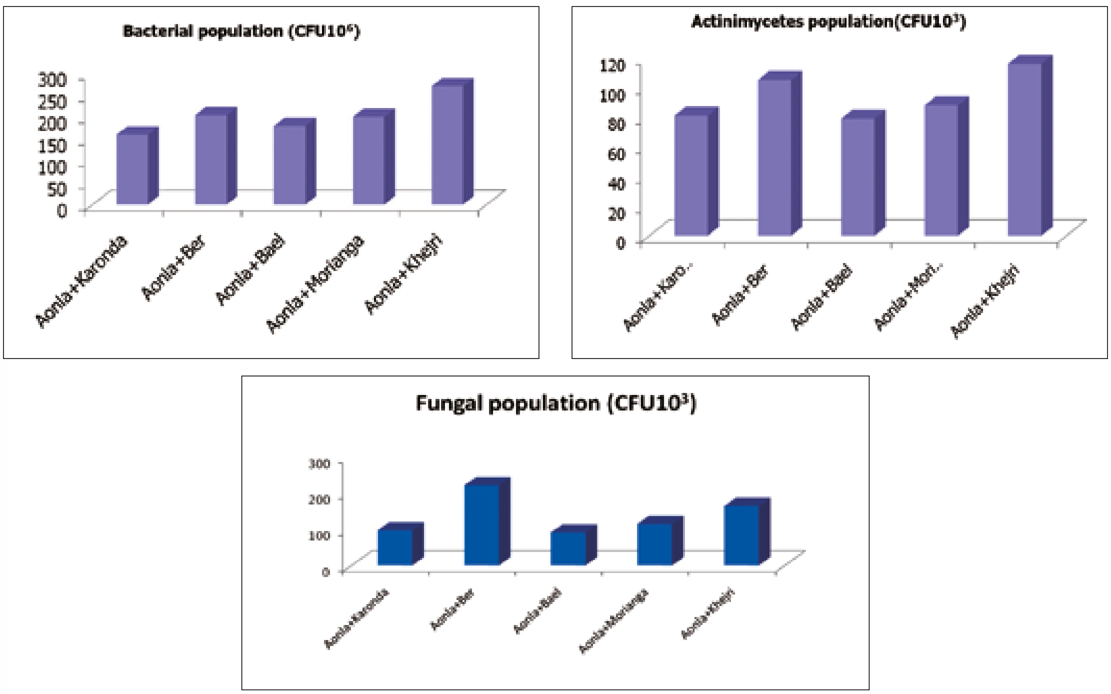

Fig. 17. Effect of *aonla* based cropping model systems on microbial population in the soil.

vi. Fruit quality characteristics

Aonla fruits were analysed for their quality characteristics like sugars, acidity, ascorbic acid, polyphenols, flavonoids, flavanols and total antioxidant activity. *Aonla* sole crop registered lowest contents for most of the parameters studied except TSS, acidity and sugars. Not much variation was noted for different quality attributes in *aonla* among the various cropping systems. However, antioxidant contents and total antioxidant activities were found to be slightly higher in cropping combinations than the sole crop (Table 12).

Table 12. Quality characteristics of *aonla* under different cropping systems.

Attributes	Cropping systems				
	***Aonla* (sole crop)**	***Aonla-Bael***	***Aonla-Ber***	***Aonla-Khejri***	***Aonla-Moringa***
Ascorbic acid (mg/100 g)	283.3	314.5	320.1	316.2	321.8
0-dihydric phenol (mg /100 g)	29.30	29.60	32.00	33.00	30.10
Polyphenols (mg /100 g)	54.16	57.38	57.27	57.11	56.32
Flavonoids (mg /100 g)	147.30	155.67	218.61	175.80	149.59
Flavanols (mg /100 g)	13.11	13.26	16.65	14.49	13.75
Total antioxidant activities (MTE/ 100g)	20.5	21.3	23.2	21.7	22.0

vii. Impact of canopy on over, under and ground storey crops

For most of the combinations of perennial and annual crops, no negative allelopathic effects of over storey crops (*aonla*, *ber*, *khejri*, *karonda*, moringa) on growth and production potential of ground storey crops (*ajwain*, coriander, dill, mustard, *methi* and cluster bean) was observed (CIAH, 2013). This was further confirmed by laboratory assay through seed germination tests conducted on rhizospheric soils. However, inhibitory effect was recorded in few cropping combinations as indicated below;

Table 13. Impact of fruit crops on ground storey crops.

Fruit crop	Ground storey crop	Allelopathic reaction
Aonla	Chick pea	(-)
Aonla	Moth bean	(-)
Ber	Moth bean	(-)
Khejri and *bael*	Chick pea, cluster bean and moth bean	(+)
Ber, Aonla	Mustard	(-)

viii. Cash-flow and economic analyses

By adopting the present cropping system, one can ensure harvest of produce for most part of a year and; thus, regular income from the same piece of land. The cash flow from fruit based cropping system had been depicted in Fig. 18.

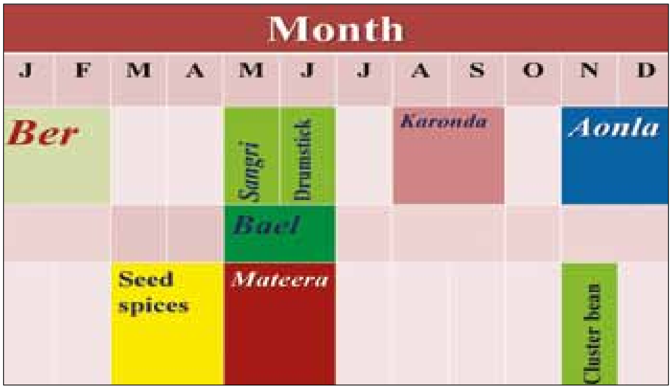

Fig. 18. Cash-flow from *aonla* based cropping systems.

Economic analyses of different fruit based cropping system models viz., Aonla-Ber-Cluster bean-Fennel, *Aonla-Bael*-Cluster bean-Coriander, *Aonla-Khejri*-Cluster bean-*Ajwain* and *Aonla*-Drumstick-Cluster bean-Dill showed that upon expenditure of inputs valued Rs. 30,000-45,000 an output of worth Rs.101,002; 1,00,044; 1,0,872 and 1,20,300 can be obtained; thereby, the realization of net return of Rs. 101, 500; 79,700; 91,300 and 71,716, respectively (Table 14).

Table 14. Economic analyses of different fruit based cropping system models.

Cropping models	*Aonla* yield/ Plant (kg/ tree)	Component tree yield (kg/ tree)	Cluster bean yield (q/ ha)	Yield of seed spices (q/ha)	Return from *Aonla*	Return from component tree crops (D)	Return from Cluster bean (D)	Return from seed spices (D)	Gross return (D)	Cost of cultivation (D)	Net return (D)	B:C ratio
Aonla	46	0	0.00	0	71760	0	0	0	71760	30000	41760	1.4
Aonla + Ber + Fennel	54.7	52.3	4.50	4	85332	20920	15750	24000	146002	45000	101002	2.2
Aonla + Bael + Coriander	53.4	25.3	5.00	3	83304	20240	17500	24000	145044	45000	100044	2.2
Aonla + Khejri + Ajwain	56.2	11.25	4.20	2	87672	40500	14700	10000	152872	45000	107872	2.4
Aonla + Drum stick + Dill	50.6	15.6	6.12	2.8	78936	9360	21420	7000	116716	45000	71716	1.6

It was noted that fruit based diversified cropping has resulted in the increase in the essential relevant elements in soil, which in turn might have improved plant growth attributes, physical, chemical and biological attributes of the rhizospheric soil and *Aonla+Khejri* followed by *Aonla+Ber/ Bael* system were found to be superior than any other cropping systems for arid conditions.

e. *Ber* based cropping system

Owing to great uncertainty in production monocrop culture in arid region is highly risk prone. Crop failures are common and lead to great economic losses. Therefore, planting of more than one fruit species in combination can ensure some production in case a particular crop fails. During young age of the orchard, short duration fruits or crops can be grown as filler or as intercrop. While selecting a filler or intercrop, its suitability in the region with respect to growth, flowering and fruiting seasons and market demand must be considered. Growing of vegetable crops, pearl millet, moth bean, cluster bean, and gram between the trees of *Ziziphus nummularia* (*Jharber*), *Ziziphus rotundifolia* (*Bordi*) and *Z. mauritiana* is a prevalent traditional practice in the arid region. *Ber* plants after planting cover the entire inter-row spaces in a period of about 5 years under rain fed conditions. During this period, considerable loss in soil health particularly soil erosion occurs from these vacant interspaces. By inclusion of suitable intercrops during rainy season, these losses can be minimized and additional income may be generated. Inter-cropping in newly developed *ber* orchard had no adverse effects on plant growth up to 5 years. However in subsequent years, tall growing crops like pearl millet and *guar* were adversely affected and the effect was perceptible up to 2.5 m distance (Bhandari *et al.*, 2014). Studies revealed that the yields of both *ber* and the intercrops were higher than in monoculture (Singh, 1997). Intercropping of *guar*, green gram and sesame with *ber* (cv. Seb) increased the fruit yield to 14.8 from 5.2 kg tree^{-1}. Cultivation of *guar* in this system gave additional advantage of 782 kg seed yield, which was higher than that obtained from green gram and cowpea in drought years. However, Gupta *et al.* (2000) reported that 3-year old plantation of jujube at a density of 400 plant ha^{-1}in association with green gram performed well with seasonal rainfall of 210 mm. Intercropped green gram yielded only 160 kg ha^{-1} as against 620 kg ha^{-1} from pure crop, but the fruit yield from intercropped system increased the net profit to D 2886. The economic analysis of cost and returns of jujube and Indian gooseberry based agri-horti systems revealed that highest net profit of D 13,487 from one hectare was realized from jujube with *guar* followed by 11,700/- from jujube with green gram (Meghwal and Henry, 2006). Jujube, being a multipurpose species provided better income and interspaces were best utilized for growing of leguminous crops. Least gross return and negative profits were obtained from Indian gooseberry with *guar*, since fruit plants were just 3 years old without bearing of fruits; nevertheless an additional income of D 3720 from a hectare was obtained just by growing *guar*, which met out 79 % of the expenditure on maintaining this system. The highest B:C ratio (2.15) was achieved in jujube and *guar* followed by sole plantation of jujube (2.10) and jujube with green gram (2.02), which was higher than the B:C ratio obtained by either of sole crops. This shows that agri-horti system minimizes the risk and helps in imparting economic stability. Cover cropping with *lobia* (*Dolichos biflorus*) was found to increase water holding capacity of light soils as a result of increased organic carbon content in these regions (Pareek and Nath, 1996).

Similarly, crops like pearl millet, cluster bean and moth bean grow in association with *jharber* even on soil sediments in rocky plateaus near Jaisalmer and Jodhpur. Cluster bean has been found to be a good intercrop at all the locations. Agri-horti system involving *Z. rotundifolia* + *V. radiata/ V. aconitifolia/ C. tetragonoloba* and *Z. mauritiana* + *V. radiata/ C. tetragonoloba* have been found environmental friendly and economically viable even during drought years. 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 (Faroda, 1998). Intercropping in newly planted *ber* orchard had no adverse effect on plant growth up to 5 years. The intercrop also exhibited higher yield when planted with *ber* compared to monoculture under rain fed conditions. Agri-horti system comprising *Ziziphus* + *mung* bean provided fruit, fuel wood and round year employment even in below average rainfall year (Sharma and Gupta, 2001). Earlier, Gupta *et al.* (2000) reported that three year old plantation of *ber* (*Z. mauritiana*) at a density of 400 plants/ha in association with green gram performed very well with a seasonal rainfall of 210mm. Intercropped green gram yielded only 160 Kg ha^{-1} as against 620 kg ha^{-1} from pure crop. The fruit yield from the intercropped system increased the net profit to 2, 886. This shows that this Horti-agri system minimizes the risk in arid regions and helps in imparting economic stability. This system is however generally recommended for areas with rainfall more than 250-300mm. Likewise, according to Singh *et al*. (2003) intercropping of legumes with *ber* orchard produced higher grain yield of intercrops by 5-20% over their sole cropping and intercropping is promising particularly during juvenile period of fruit plantation. Under arid conditions, strong competition has however, been observed between *ber* trees and crops like wheat (Pateria *et al*., 2005) and chickpea (Khan, 1993). It has been suggested that the cost of keeping *Ziziphus* trees was more than the value foregone by growing these crops. Thus such crops should not be grown in *ber* orchards. Cover cropping with *kulthi* (*Dolichos biflorus*) was found to increase water holding capacity of light soils as a result of increased organic carbon content in arid region in the tropics (Pareek and Nath, 1996). Tree-crop interactions studied under different conditions revealed useful interaction of annual crops with *ber* (Rao, 2009). The promising intercrops with *ber* at different locations were pearl millet + pigeon pea (at Solapur), blackgram and pigeon pea (at Rewa), castor (at Dantiwada), all pulse crops (at Agra and Hisar) and cluster bean (at Hyderabad).

Similarly, an experiment conducted at CAZRI-RRS, Bikaner revealed that intercropping of annual crops with fruit trees provides the extra income to farmers when fruit trees are in their juvenile phase (Yadava *et al*., 2006). Highest total income and net profit was realized with *bael* + groundnut intercropping followed by *ber* +groundnut and Kinnow + groundnut. The highest B:C ratio was recorded with *bael* + cluster bean followed by *bael* + Moth bean (Table 15).

Table 15. Economics of different agri-horti system in District Bikaner.

Agri-horti system	Net profit (Rs ha^{-1})	B:C Ratio
Ber + Moth bean	10854.0	2.06
Ber + Cluster bean	12970	2.33
Ber + Groundnut	20379	2.45
Bael + Moth bean	14310	2.86
Bael + Cluster bean	16054	3.02
Bael + Groundnut	21799	2.75
Kinnow + Moth bean	11015	2.20
Kinnow + Cluster bean	11122	2.10
Kinnow + Groundnut	19830	2.50

f. *Ber* based cropping system: experience at ICAR-CIAH, Bikaner

Under hot arid eco-system of western Rajasthan (Bikaner), studies on *Ber* based Agri-Horti system was investigated by Saroj *et al.* (2003). *In situ* budded *ber* cv. Gola with three spacings (6x6m, 8x8m and 16x4m) as overstorey component and groundnut (*Arachis hypogia*), wheat (*Triticum aestivum*), cluster bean (*Cyamopsis tetragonolobus*), mustard (*Brassica juncea*) and indian aloe (*Aloe barbadensis*) as ground storey components were integrated into the system. Different crop combinations such as *Ber* + Wheat – Groundnut, *Ber* + Clusterbean – Mustard, *Ber* + Indian Aloe and Sole *ber* were evaluated. During the initial stage of its establishment, there was no competition between groundstorey and overstorey components for resources. Instead, the inputs applied for the groundstorey crops enhanced the vegetative vigour of *ber* plants than sole plantation. Among the different crop combinations, the highest yield of *ber* was recorded with Indian aloe (13.55 q ha^{-1}) while 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}) (Table 16). 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 (Table 17). The cash flow from *ber* based cropping system has been depicted in Fig. 19. Conclusive results of the study indicated that cluster bean- mustard and Indian aloe can be integrated as a compatible ground storey component with *ber* as compared to ground nut-wheat, which is a dominant rotation in the irrigated hot arid ecosystem. Further, results showed that the wider spacing can be followed for taking intercrops on long term basis, else standard spacing can be followed to take intercrops only during the pre-bearing phase of *ber* orachards. To optimize productivity and profitability during pre-establishment phase of *ber* orchard under same agro eco-system, association of cluster bean-mustard and Indian aloe as a groundstorey component with *ber* cv. Gola have been recommended (Dhandar *et al*., 2004). These crops have been identified as low input and high returning crops giving net returns of 65, 802 and 26, 144 ha^{-1}, respectively. Likewise in the arid sandy plains at Jodhpur horti-pastoral management growing buffer grass was found better. Leguminous crop can be preferred as they also enrich the nitrogen in the soil. In irrigated areas, pea, gram, cumin, chilies, fenugreek can be taken whereas, under rainfed conditions *moong*, moth cowpea and *guar* can be taken during *Kharif* season.

Table 16. Yield of *ber* fruits (q/ha).

Crop rotation	Spacing			
	6 x 6	8 x 8	16 x 4	mean
Ground nut-Wheat	13.37 (4.81)#	7.64 (4.90)	7.86 (5.04)	9.62 (4.92)
Cluster bean -Wheat	13.81 (4.97)	7.83 (5.02)	7.77 (0.98)	9.80 (4.99)
Indian aloe	19.13 (6.88)	10.76 (6.90)	10.76 (6.90)	13.55 (6.89)
Sole plantation	11.45 (4.12)	6.54 (4.03)	6.54 (4.19)	8.09 (4.11)
Mean	14.44 (5.20)	8.13 (5.21)	8.23 (5.26)	
CD (5%)		0.05636	0.11272	

#*Yield of individual ber plants (kg plant^{-1})*

Fig. 19. Cash flow from *ber* based cropping system.

Table 17. Yield of groundstorey crops (q ha^{-1}).

Spacing (m)	*Kharif*						*Rabi*						Perennial			
	Groundnut			Cluster bean			Wheat			Mustard			Indian Aloe			
	2001	2002	Mean	2001	2002	Mean	2002	2003	Mean	2002	2003	Mean	2001	2002	2003	Mean
6x6	5.34 (0.05)	1.56 (0.03)	3.45	91.41 (0.76)	9.83 (0.07)	50.62	3.36 (0.09)	17.79 (0.16)	1058	9.11 (0.07)	14.24 (0.55)	11.68	17.90 (0.25)	69.0 (1.10)	69.03 (1.13)	51.98
8x8	5.36 (0.08)	1.59 (0.05)	3.47	90.78 ()0.51	10.09 (0.09)	50.44	3.42 (0.10)	17.14 (0.30)	10.28	9.13 (0.09)	13.78 (0.18)	11.46	18.50 (0.24)	68.61 (1.53)	70.68 (0.53)	52.60
16x4	5.37 (0.06)	1.58 (0.04)	3.47	91.37 (0.41)	10.62 (0.08)	50.99	3.37 (0.07)	16.57 (0.40)	9.97	9.11 (0.09)	14.26 (0.48)	11.69	18.07 (0.13)	69.51 (1.17)	71.61 (0.79)	53.06
Sole Cropping	5.46 (0.04)	1.62 (0.02)	3.54	92.80 (0.43)	10.85 (0.07)	51.83	3.49 (0.09)	15.21 (0.15)	9.35	9.23 (0.05)	13.07 (0.22)	11.15	18.40 (0.25)	72.87 (1.77)	75.60 (1.11)	55.62
Mean	5.38	1.59		91.59	10.35		3.41	16.68		9.14	13.84		18.22	69.77	71.73	
CD(5%)	0.12383	0.07586		1.24189	0.16825		0.20653	0.60895		0.17028	0.89792		0.47021	3.26577	2.05893	

ii. Impact of canopy on over, under and ground storey crops

A number of annual crops are intercropped with *ber* traditionally without ascertaining the interferences between the components integrated on a land management unit. In general, growers are ignorant about the competition particularly the adverse effect of fully grown up perennial trees on annual crops, which are grown in its association through addition of allelochemicals in soil (allelopathy). Saroj *et al*. (2002) treated seeds of four test crops *viz*., groundnut, cluster bean, wheat and mustard with leaf aqueous extracts of *ber* under laboratory conditions and observed that the seed germination of mustard was significantly inhibited by *ber* leaf extracts and the reduction was 77.60 per cent over control (treated with distilled water), whereas, the germination of wheat did not influence significantly but it was reduced to some extent. In case of groundnut and cluster bean, the response on vigour parameters exhibited variable trend. There was no significant difference in shoot length between treated and control plants except in case of mustard, where shoot length reduced significantly. In general, the root length of treated plants was more affected than shoot length except in cluster bean. The other vigour parameters like number of roots per plant, root shoot ratio and vigour index also showed almost same trend. The seedling phytomass in terms of fresh and dry weight did not vary significantly in all the crops with the treatment of *ber* leaf extracts. Among different groundstorey crops, the water-soluble allelochemicals of *ber* leaf extracts had maximum inhibitory effect on mustard and minimum on cluster bean with respect to germination, seedling vigour and seedling phytomass while other crops showed variable response exhibiting sensitivity in one character and tolerance in another (Table 18).

Table 18. Effect of *ber* leaf aquous extracts on seed germination, seedling vigour and phytomass production of ground storey crops.

Ground storey crops parameter	Response		Reduction (%)	't' value
	Treated	Control		
Groundnut				
Germination (%)	87.600	94.200	6.600	5.7886 (-0.0004)
Shoot length (cm)	15.720	18.160	13.440	2.1079 (0.0681)
Root Length (cm)	6.540	10.160	36.480	6.4330 (0.0002)
No. of roots/plant	4.000	6.200	35.480	1.7720 (0.1140)
Root shoot	0.420	0.570	-	--
Vigour index	1377.070	1710.670	-	-
Fresh weight (g)	2.163	2.862	24.420	1.3590 (0.2111)
Dry weight (g)	0.394	0.461	14.530	1.3840 (0.2030)
Cluster bean				
Germination (%)	95.200	98.000	2.800	5.7150 (0.0004)
Shoot length (cm)	6.900	7.060	1.420	0.1556 (0.8800)
Root Length (cm)	6.240	6.340	1.580	0.1639 (0.8730)
No. of roots/plant	2.680	2.660	-0.750	0.1118 (0.9137)
Root shoot	0.900	0.900	-	--
Vigour index	1787.860	2101.120	-	--
Fresh weight (g)	0.229	0.217	-5.529	0.2670 (0.7960)
Dry weight (g)	0.021	0.019	-10.526	0.3840 (0.7100)
Wheat				
Germination (%)	96.600	98.400	1.800	1.3720 (0.207)
Shoot length (cm)	6.260	7.380	15.180	3.0040 (0.017)
Root Length (cm)	5.180	13.980	62.940	12.4220 (0.0001)
No. of roots/plant	2.200	4.200	47.620	3.7790 (0.0054)
Root shoot	0.830	1.890	-	--
Vigour index	604.720	726.190	-	--
Fresh weight (g)	0.203	0.267	23.970	4.9271 (0.0012)

Ground storey crops parameter	Response		Reduction (%)	't' value
	Treated	Control		
Dry weight (g)	0.064	0.066	3.030	0.2680 (0.795)
Mustard				
Germination (%)	13.600	91.200	77.600	39.8080 (0.0001)
Shoot length (cm)	4.840	7.200	32.780	6.6320 (0.0002)
Root Length (cm)	4.220	6.720	37.200	3.8310 (0.005)
No. of roots/plant	2.400	4.600	47.830	3.3940 (0.0094)
Root shoot	0.870	0.930	-	--
Vigour index	65.820	656.640	-	--
Fresh weight (g)	0.108	0.158	31.645	0.6725 (0.52)
Dry weight (g)	0.013	0.012	-8.330	1.3850 (0.203)

** Adopted from Saroj et al. (2002).*

Prosopis cineraria based system

P. cineraria, commonly known as *khejri*, is regarded as the life line tree of the Indian desert. It is an indigenous tree of the north-western plains and gently undulating ravine lands of India. This important multipurpose species provides nutritious edible pods and fuel wood to the human beings and nutritious leaf forage to the animals. The pods are rich in proteins, carbohydrates and minerals besides the nutritious leaf fodder and fuel wood (Awasthi, 2018). The tender pods are eaten green or dried after boiling locally called *sangri* and used in the preparation of curries and pickles. Ripe pods are sweet, which contain 9-14% crude protein, 6-16% sugar (Bhandari *et al*., 1978) 1.0-3.4% reducing sugars (Gupta *et al*., 1984) and 45-55 % carbohydrate (Jatarsa and Paroda, 1981). The pods are also used as feed for animals. Green *khejri* leaves are nutritionally very rich and contain 11.9-18.0% crude protein, 13-22% crude fibre, 43.5% nitrogen free extract, 6-8% ash, 2.9% ether extract, 2.1% calcium, 0.4% phosphorus with high calorific value. Tree provides excellent firewood (calorific value, ca. 5, 000 kcal/kg) and charcoal.

Farmers in the hot Indian arid zone grow arable crops in association with *Prosopis* (Table 19). In fact, such integration of arable crops with *Prosopis* trees in the farming systems is a unique, combined, protective-productive system that works on the principles of ecology, productivity, economics, and sustainability (Sharma, 2002). *Prosopis* tree has mono-layered canopy and root system that does not interfere with the annual crops as most of it lies below 50-60cm depth (Ahuja, 1981). In the alluvial plains of Jodhpur, Barmer, Nagaur and parts of Pali, crops like *jowar*, pearl millet, moth bean, cluster bean and sesame are grown during *kharif* season between the scattered khejri trees. Barley (*Hordeum vulgare*), pearl millet, *toria* (*B. tournefortii*) and chickpea are the common intercrops grown in Haryana. Puri *et al*. (1992, 1994) observed 86% higher grain yield of barley in association with *khejri*. Besides, the yield of chickpea also improved and resulted in higher soil fertility and moisture conservation. Vashishtha and Saroj (2000) reported that the vegetative vigour of *ber, aonla*, guava, *bael* and pomegranate was better during initial years when they were grown with *khejri* as compared to sole plantation of these fruit crops. Singh *et al.* (2012) while studying the changes in soil properties under tree species reported that the nutrient return through litter fall of *Prosopis cineraria* followed the order Ca> N>K. Mann and Shankarnarayana (1980) reported improvement in organic matter status, total nitrogen, available phosphorus, soluble calcium and decreases pH on the sites planted with *P. cineraria*.

Maximum net return (Rs.15, 197/ha) and benefit-cost ratio (3.73) were obtained when pearl millet in *kharif* was followed by toria in *rabi* between the khejri trees (Kaushik and Kumar, 2003). Yield of fodder crops during both *kharif* and *rabi* seasons was higher in association with *khejri* trees as compared to sole cropping.

Table 19. *Prosopis* based traditional cropping systems prevalent in hot arid regions*.

Crop combination	Annual rainfall (mm)	Habitats	Associations of crops/grasses
Prosopis-Ziziphus-Capparis	250–300	Alluvial plains, soils, often with kankar pans at 80-150 cm soil depth	Pearl millet, cluster bean, green gram, moth bean, sesame; *Cenchrus ciliaris* with *C. setigerus*
Prosopis-Tecomella	275–325	Sandy undulating plains	Pearl millet, cluster bean, green gram, moth bean- *Cenchrus ciliaris* with *C. setigerus*
Prosopis	300–350	Alluvial plains	Pearl millet, cluster bean, green gram, moth bean- *Cenchrus ciliaris*
Prosopis-Acacia	300–350	Alluvial plains (irrigated)	Sorghum, cumin, pearl millet, mustard, wheat

** Adopted from Sharma (2002).*

g. Cordia based system

Cordia myxa or 'cherry' of the desert and also known as sebesten *lehsua*, *lasoda*, *gunda*, *lehtora*, Assyrian Plum, Bird's Nest etc., is found growing abundantly in Rajasthan, Punjab, Haryana, Uttar Pradesh, Madhya Pradesh, Chattisgarh, Gujarat, Maharashtra, Assam and Khasi hills. *Cordia* is suitable tree for agri-horticulture, horti-pastoral and agri-silvi-horti systems in arid regions. To get additional income and proper utilization of interspace, intercropping is advisable by selecting judicious crop combinations. During survey different crop combinations with *Cordia* were observed by Singh *et al.* (1996).

Table 20. *Cordia* based cropping system in arid zone.

Location	Av. Rainfall (mm)	Crops	
		Rainfed	Irrigated
Jodhpur (Pipad)	290	Pearl millet, cluster bean	Rapeseed, mustard, wheat, green gram
Pali and adjoining areas	490	Vegetables, pearl millet, cluster bean, taramira	Raya, wheat, green gram
Jalore Sirohi	434 544	Vegetables/spices, cluster bean, pearl millet	Rape seed, mustard
Bikaner Barmer	243 350	Pearl millet	Rape seed, mustard

h. *Salvadora* based cropping system

Two species of *Salvadora i.e., S. persica* (*meetha jaal*) and *S. oleoides* (*khara jaal*) are available in India. *Meetha jaal* is an edible species, while the *khara jaal* is used for extraction of oil from seed, which is used for preparation of wax candle and soap. In alluvial plains with annual rainfall of 250-300mm and where soils are moderately saline, *Salvadora* is, conventionally, grown in association with perennial components like *Prosopis* and *Capparis* sp. and annual components cluster bean, pearl millet and sesame (under rainfed) and wheat (irrigated areas) along with grasses such as with *Cenchrus setigerus* and *Sporobolus* sp. (Sharma, 2002).

S. oleoides is also suitable for run off farming or *khadin* system (low lying depression zones, which are normally used for grazing and are used as catchments for efficiently harvesting the runoff water. In Kutch, Gujarat, *Saldvadora* has successfully been grown in combination with *Urochondra sendosa*, *Juncus maritimus* and *Citrullus colocynthis* as sources of fiber, paper pulp, and pharmaceutical compounds, respectively, while *Suaeda maritima* was used for fixing sand dunes (Anon., 1997).

10. Conclusion

Fruit based diversified cropping system is a quite encouraging proposition for minimization of risk of total crop failure, particularly, under fragile ecosystem of arid regions. Integration of crops with diverse growth habits, growing/fruiting seasons and input requirements not only help ensuring efficient management of available resources but also round the year harvest of a wide range of produce. Integration of seasonal crops with fruit trees is a viable approach for enhancing system productivity (Saroj and Krishna, 2017).

A gamut of crop species has been found to be suitable, in terms of their resilience under challenging environment, for inclusion in the cropping system; however, more research need to be taken up for validation of the different systems tailor-made for specific agro-ecological situations, keeping in view ever-changing requirement of the regions and consumer's preferences.

11. Challenges for future research

- Some traditional fruit tree based systems do increase crops yields near trees; however, there are instances where fast growing trees have reduced crop yields in the short term. Therefore, case-specific long term studies are needed to be carried out to resolve this issue (Singh and Pandey, 2011).
- Perennial fruit trees are known to be associated with improved soil nutrient supply in traditional tree based systems. However, it is not established if they additionally supply nutrients by increasing the total quantum of nutrients in agro-ecosystems or simply redistribute the available quantity horizontally and vertically.
- High water use by fast-growing, deep rooted trees and therefore supposed groundwater depletion is a common concern in dry regions, which hitherto remains unanswered. Do trees actually extract more groundwater or use the residual water available either through irrigation, or use the rainwater when crops have been harvested? It could be possible that rather than allowing the rains be lost as runoff, fruit tree based system may increase the utilization of rainwater by extending the growing season. In addition, it is not clearly understood if trees harvest and accumulate water from surrounding area and release it during the soil-moisture stress. If this is so then, fruit tree based cropping system as an adaptation to monsoon variability may actually benefit the crops (Singh and Pandey, 2011).
- Studies on the carbon sequestration potential are limited both by their location specificity as well as uncertainty related to sequestration in biomass and soils. Quite often, the rate of carbon sequestration is derived from the growth of above ground biomass. In addition, role of such cropping systems in as an adaptation to climate change needs to be ascertained further.
- Fruit based systems with mature trees are known to yield enough litter, which conserve soils and ameliorate soil nutrient status, but knowledge on the full range of fruit tree species and their attributes useful for all the agro-climatic regions and problem-soils in India are required.
- There is a need to identify the multiple-use fruit species with a wide range of edaphic adaptation in order to increase the adoptability of such cropping system among farmers. This is a crucial area of research involving multi-location research across the arid regions in India.
- Many wild populations of fruit species, which yield commercially-valued products are gradually getting diminished; therefore, research efforts are required to domesticate these species and integrate with the fruit based cropping systems.
- Policies need to be made for strengthening linkages between markets and fruit tree based by-products.
- Since many fruit tree produces fruits with lower shelf life; therefore, vigorous efforts are needed to provide knowledge on the on-farm value addition innovation.

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