Agroforest Syst (2016) 90:1123–1132
DOI 10.1007/s10457-015-9889-4

Fruit-based agroforestry systems for saline water-irrigated semi-arid hyperthermic camborthids soils of north-west India

J. C. Dagar · R. K. Yadav · O. S. Tomar · P. S. Minhas · Gajender Yadav · Khajanchi Lal

Received: 22 January 2015 / Accepted: 17 December 2015 / Published online: 28 December 2015

Abstract Large areas in arid and semi-arid regions remain barren due to lack of irrigation. The underground aquifers in these regions are either saline or sodic. Groundwater surveys indicate that poor-quality water is used to irrigate arable crops in 25–84 % of the total groundwater development areas in north-western states of India. The present long-term study assessed the performance of low-water-requiring, salt-tolerant fruit-based (*Carissa carandas*, *Emblica officinalis*, *Aegle marmelos*) agroforestry systems with saline irrigation under sem-iarid conditions. The companion crops such as *Hordeum vulgare* for malt, *Brassica juncea*, a seed oil (winter), and *Cyamopsis tetragonoloba* for gum and *Pennisetum typhoides*, a coarse grain/fodder (summer), were grown in inter-row spaces. The fruit trees were successfully established in the sill of furrows using low (EC 4–5 dS m^{-1}) salinity water. Subsequently, all the systems were irrigated with water of low and high (8.5–10.0 dS m^{-1}) salinity and their alternate use as per treatments. Fruit yields under alternate and high saline irrigation reduced by 18–27.5 % in *Carissa*, 41.6 % in *Emblica* and 31.7–54.8 % in *Aegle,* respectively. There was no significant reduction in grain yields of *Pennisetum* and *Hordeum.* However, in subsequent years, the seed yields of *Cyamopsis* and *Brassica* reduced with saline water and more so when intercropped with *Aegle*. *Carissa* with *Pennisetum* and *Hordeum* performed best with saline water. The study shows that saline water (ECiw up to 10 dS m^{-1}) could be used sustainably for these fruit-based agroforestry systems without significant salinity build-up in sandy loam calcareous soils. Thus, such fruit-based agroforestry systems could be a viable option for the areas with only saline groundwater available for irrigation.

Keywords Fruit-based agroforestry · Saline irrigation · Calcareous soils · Fruit yield · Crop yield · Soil salinity

J. C. Dagar · R. K. Yadav (✉) · O. S. Tomar · G. Yadav
Central Soil Salinity Research Institute, Karnal, Haryana 132001, India
e-mail: RK.Yadav@icar.gov.in

P. S. Minhas
National Institute of Abiotic Stress Management (Deemed to be University), Malegaon, Baramati, Pune, Maharashtra 413 115, India

K. Lal
Water Technology Centre, Indian Agricultural Research Institute, New Delhi 110012, India

Introduction

Vast tracts of land in arid and semi-arid regions throughout world remain barren due to scanty and uneven distribution of rainfall that results in water scarcity (Armitage 1984). Such lands usually lack fresh water supplies for irrigation, except for the very deep, low yielding and mostly saline groundwater aquifers. In India, most of these lands (~127.3 mha) continue to be underutilized and remain fallow throughout the year (MoA 2012; Dagar et al. 2013). Groundwater surveys indicate that 25–84 % of the total groundwater development in the country is poor in quality that is being utilized for irrigation, especially in Rajasthan, Gujarat, Haryana and Punjab (GoI 1998).

In the past, efforts towards utilization of saline groundwater confined to enhance the production of annual arable crops. Some viable technologies have been suggested to sustain the use of saline groundwater for irrigation in arable crops, forage grasses, medicinal and aromatic plants and even for establishing the forest and fruit trees (Minhas 1996; Bouwer 2002; Tomar et al. 2003a, b, 2010; Qadar et al. 2007, 2008; Dagar et al. 2008, 2013). The traditional approach of sustainable use of saline water has been to increase the frequency of irrigation, which leaches down the salts below the shallower rhizosphere of arable crops (Ayers and Westcot 1985; Dagar et al. 2008). However, enhanced frequency of saline water irrigation may rather aggravate the problem in deep rooted woody vegetation, because of the additional salt loads going into the soil that likely to persist within the root zone, and may subsequently hinder the plant growth. Nevertheless, such practice demands additional quantities of saline water and thereby results in enhancement of overall salt loads in the soils.

Developing low-water-requiring fruit-based agroforestry systems for the dry regions having saline groundwater as the only source of irrigation could be ecologically sustainable and help in improving the socio-economic conditions of the people. This implies the need for long-term evaluation trials for tree species and also to evaluate their suitability to site conditions. Some researchers (Shalhevet 1984; Rogers 1985; Morris et al. 1994; Tomar et al. 2003b) have also recommended a period of at least 5–8 years for such evaluation trials. Moreover, no such efforts have been made to evaluate fruit trees in combination with arable crops as agroforestry systems with saline irrigation. Therefore, a long-term study was undertaken to assess the performance of salt-tolerant, fruit-based (*Carissa carandas*, *Aegle marmelos,* and *Emblica officinalis)* agroforestry systems with *Hordeum vulgare* and *Brassica juncea* during winter and *Pennisetum typhoides* and *Cyamopsis tetragonoloba* during rainy season as companion crops in the inter-spaces between tree rows under saline water irrigation in a semi-arid region of north-west India.

Materials and methods

Site and climate characteristics

The experimental site, Bir Reserved Forest Hisar, is located in north-west part of India at 29°10′N longitude and 75°44′E latitude with an altitude of 240 m above mean sea level. Before starting of the experiment, the site had sparse vegetation comprising of shrubs and bushes, predominantly *Prosopis juliflora, Capparis deciduas, Ziziphus numularia* and *Calotropis procera*, and herbaceous species like *Sporobolus marginatus, Dactyloctenium scindicum, Cynodon dactylon, Cenchrus ciliaris* and *Tribulus terestris*. The soils of the site are highly calcareous sandy loam hyperthermic camborthids. Calcareousness is the major impediment in tree growth as the calcite ($CaCO_3$) content varied between 2 and 15.8 % (average 7.5 %) and increased with soil depth. The general climate of the study site is semi-arid monsoon type. Average annual rainfall of the site was 499 mm (from 1991 to 2011), the most (70–80 %) of which occurs during July–September. The mean open pan evaporation during the same period was 1930 mm. The reported weather data were recorded at the meteorological observatory of CCS Haryana Agricultural University, Hisar.

The annual rainfall and mean open pan evaporation during the study period (2002–2011) were 507 and 1896 mm, respectively with the mean daily maximum and minimum temperatures of 31.3 and 16.3 °C, respectively (Fig. 1). The annual rainfall ranged from 321 mm (during 2004) to 775 mm (during 2010), and the open pan evaporation was maximum (2283 mm) in 2002 and minimum (1585 mm) in 2011.

Site preparation and experimental design

The bushes and other vegetation were cleaned, and land was thoroughly ploughed 4 times harrowing followed by 2 times passing of cultivator and precisely levelled with a gradient of 0.1 % during June 2002. Thereafter, the field experiment in factorial randomized block design with three replications was laid out by creating furrows (0.15 m deep and 0.6 m wide) at a 5-m distance with a tractor drawn furrow maker and digging holes with auger (0.2 m in diameter and 1.2 m deep) in the sill of the furrows at a 2-m distance in *Carissa and* 4 m in case of *Emblica* and *Aegle*. These

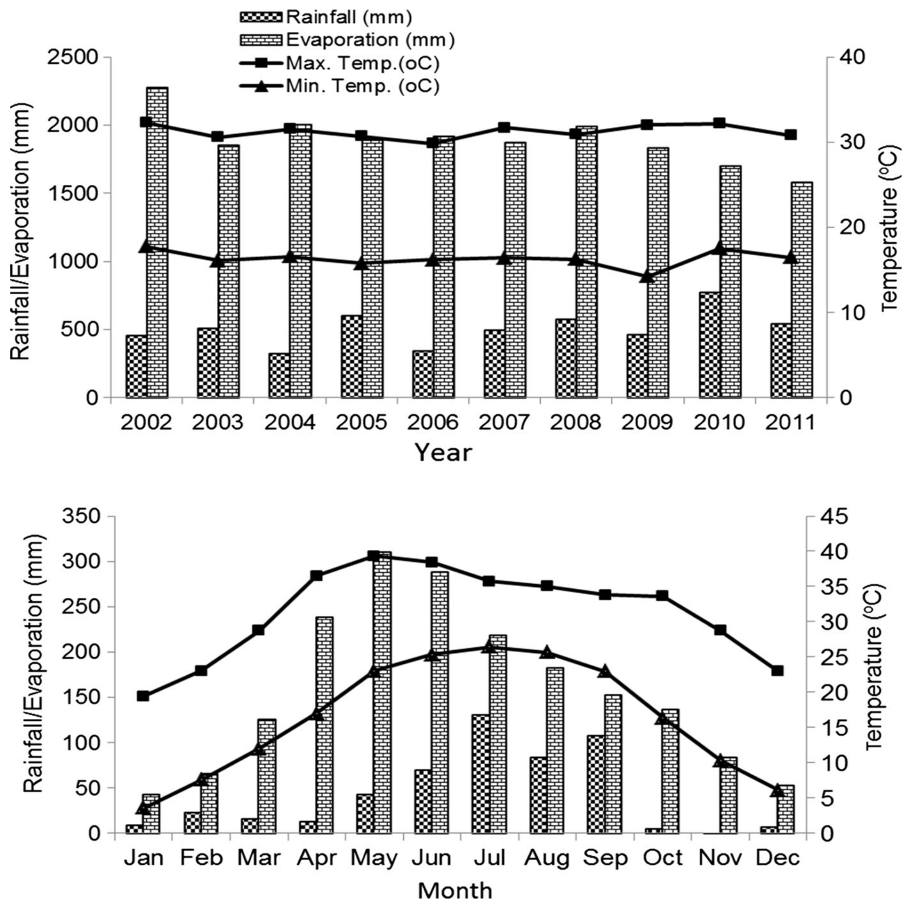

Fig. 1 Annual (*above*) and monthly (*below*) means of 10-year weather data (2002 to 2011)

auger holes were refilled with the mixture of original soil mixed with 8 kg of farmyard manure, 300 g single super-phosphate (SSP), 15 g $ZnSO_4$ and 15 g $FeSO_4$ per auger hole.

About 6- to 7-month-old saplings of fruit trees (grown in poly bags through grafting) of *Carissa carandas* Linn., *Emblica officinalis* Gaertn. and *Aegle marmelos* Correa ex Roxb. were transplanted in the refilled auger holes during July 2002. The saplings were irrigated using low salinity water (ECiw 4–5 dS m^{-1} and SAR 18) as per the need for initial 3 months. Afterwards, differential irrigation treatments were applied using the low salinity water (T_2), alternate irrigation with low and high salinity (ECiw 8.5–10.0 dS m^{-1} and SAR 21) water (T_3) and irrigation with high salinity water (T_4). There were 10 treatment combinations in total, consisting of three fruit tree species irrigated with three levels of saline water irrigation and one control treatment of low salinity water irrigated arable crops without trees (T_1). *Carissa* was planted at 5 × 2 m row and plant distance, whereas *Emblica* and *Aegle* at a distance of 5 × 4 m. Each treatment combination of *Emblica* and *Aegle* had 12 numbers of trees each and *Carissa* had 24. Since the establishment and survival of *Emblica* was poor in the first year, gap filling was done during August 2003.

Cultivation of crops

Pennisetum typhoides (cv HHB 68) was cultivated in the inter-spaces between rows of trees during the rainy season in the first year, i.e. 2002, followed by *Hordeum vulgare* (cv BH375) and *Cyamopsis tetragonoloba* (cv HG 365) crop rotations during the years 2003 to 2007, and *Brassica juncea* (cv CS 56) and *Cyamopsis tetragonoloba* crop rotations during the years 2008 to 2011. Although the performance of *Pennisetum* was very good, it had to be replaced with *Cyamopsis* because of the problem of bird's damage (being surrounded by forest trees in neighbourhood). In general, rainy season crops were sown after onset of monsoon without pre-sowing irrigation except in the years when onset of monsoon was delayed. However, before sowing of winter season and rainy crops in delayed monsoon years, a pre-sowing irrigation of about 6 cm was applied using the low salinity water. In general, only life saving irrigations of respective quality water was given to rainy season crops; however, four and two irrigations of designated quality water as per treatment were applied every year in *Hordeum* and *Brassica*, respectively. Farm Yard Manure @ ~10 Mg ha^{-1} was applied each year at the beginning of winter season. All the arable crops were cultivated as per the recommended package of agronomic practices for the respective crops in the area.

Soil and water sampling and analysis

Before laying out the experiment, soil samples were collected from different depths at a grid of 60 × 70 m. Later on, soil samples were collected from three random places in each treatment plot twice every year, i.e. after the harvest of winter crops in April and rainy crops in November. These soil samples were air dried, ground and passed through 2 mm sieve and analysed for electrical conductivity (ECe) and pH values in the saturated paste extract as described by Richards (1954). The mechanical analysis was done using the Pipette method (Piper 1966). The water samples were collected every month from the two tube wells having low and high salinity. These water samples were analysed for Na^+ and K^+ with flame photometer, while $Ca^{2+} + Mg^{2+}$, Cl^{1-}, $CO_3{}^{2-}$ and $HCO_3{}^{1-}$ and $CaCO_3$ in soil were determined as per standard methods described by Jackson (1967). Sodium adsorption ratio (SAR) and residual alkalinity/residual sodium carbonate in water were calculated using equations (SAR = $Na^+/\sqrt{[(Ca^{2+} + Mg^{2+})]}$ and [(RSC = $(CO_3{}^{2-} + HCO_3{}^{-}) - (Ca^{+2} + Mg^{+2})$ meq l^{-1}], respectively. Average values of the some of the initial physico-chemical characteristics of the soil and water are given in Tables 1 and 2.

Growth and yield observations of fruit trees and crops

Survival and heights of all fruit tree species were recorded twice in each year during April and November, and fruit yields were recorded per bearing season of respective species. Similarly, fresh and dry biomass and grain/seed yields of all the crops were recorded from whole plot area of each treatment at harvest, converted into Mg per hectare and averaged for all the three replications.

Statistical analysis

Differences of means of various growth parameters and yields of fruits and arable crops under respective

Table 1 Initial physico-chemical properties of the experimental soils (average of 12 profiles)

Soil depth (cm)	Clay (%)	Silt (%)	Sand (%)	pH	ECe (dS m^{-1})	CaCO3 (%)	
						Range	Mean
0–15	18.6	19.6	61.8	8.3	1.6	2.0–13.0	6.2
15–30	18.4	20.5	61.1	8.2	1.7	2.6–15.2	7.2
30–60	18.0	22.2	59.8	8.1	2.0	2.6–14.2	8.4
60–90	17.6	21.5	60.9	7.9	2.6	3.2–15.8	8.0
90–120	18.2	21.4	60.4	8.0	2.9	3.0–14.8	7.8

Table 2 Chemical composition of the groundwater used for irrigation

ECiw (dS m^{-1})	pH	Na	$(Ca^{+2} + Mg^{+2})$	Cl^-	$HCO_3{}^-$	RSC	SAR (mmol $l^{-1})^{1/2}$
4–5*	8.4	34.8	7.3	17.9	7.8	1.0	18.3
8.5–10.0**	8.0	69.0	23.6	46.2	4.8	negligible	21.2

* Low salinity water

** High salinity water

Table 3 Survival (%) of fruit tree species at different periods of time

Fruit trees species	Irrigation water quality	Percent survival after (years)			
		1	3	5	7
Carissa carandas	Water with low salinity	98	100	98	98
	Water with alternate irrigation	97	100	98	98
	Water with high salinity	92	98	96	96
	Mean	96	99	97	97
Emblica officinalis	Water with low salinity	69	90	82	78
	Water with alternate irrigation	65	86	80	74
	Water with high salinity	58	80	72	68
	Mean	64	85	78	73
Aegle marmelos	Water with low salinity	95	98	94	92
	Water with alternate irrigation	93	96	90	88
	Water with high salinity	87	90	80	76
	Mean	92	95	88	85
LSD ($p = 0.05$)	Fruit tree species	23	NS	4.5	8
	Irrigation water quality	10	NS	3.8	5
	Species × irrigation water quality	NS	NS	NS	NS

After 1 year, gap filling was done in all the plantations; values with same letters in a column are not differing significantly among themselves

treatments were estimated by Analysis of Variance at 5 % level of significance using MStat C program.

Results

Performance of fruit trees

During the first year, the survival rates in three treatments of saline water irrigation, i.e. T_2, T_3 and T_4, were 92–98, 87–95 and 58–69 % in *Carissa*, *Aegle* and *Emblica*, respectively. Establishment and survival of *Emblica* was poor because of the detachment of tender roots of saplings from soil in poly bags during the long distance road transportation of nursery. Hence, to maintain the recommended stand density, gap filling was done in the subsequent year. After 3 years, the recorded survival rates were 100 % in *Carissa* and 90–98 % in *Aegle* irrespective of all the treatments of irrigation water quality. However, the least survival rates of 80, 86 and 90 % were recorded in *Emblica* under T_4, T_3 and T_2, respectively (Table 3).

There was no significant effect of irrigation water salinity on survival of *Carissa*. Survival of *Aegle* and *Emblica* was not affected under alternate irrigations with low and high salinity water but reduced significantly in high salinity water irrigation after 5 years of growth in both crops. *Carissa* and *Emblica* dried due to occurrence of very severe abnormal frost accompanied with temperatures plummeting as low as −1.3 to −2.0 °C during winter of 2005–06. However, *Carissa* regenerated completely, but *Emblica* suffered 10–20 % mortality during the following rainy season. About 75 % of the *Carissa* bushes recorded fruit bearing after regeneration and produced on an average 0.86 Mg ha^{-1} fruits.

Emblica suffered again from frost during winter of 2006–07 and also regenerated, but the crop did not bear fruits. However, Carissa produced about 0.95 Mg ha^{-1} fruits under T_2 and T_3 but relatively lower in treatment T_4. *Aegle* also started bearing fruits and produced 2.32, 1.85 and 0.96 Mg ha^{-1}, when subjected to T_2, T_3 and T_4 irrigation treatments, respectively (Table 4).

In *Carissa*, fruit yield reduced by 27.5 and 18 % with T_4 and T_3, respectively, as compared to T_2. The extent of reduction in fruit yield in *Emblica* was 41.6 % under T_4. *Aegle* produced 3.28 Mg ha^{-1} fruits with T_2, while it produced 1.48 and 2.24 Mg ha^{-1} fruits under T_4 and T_3, respectively. The extent of reductions in *Aegle* fruit yield with T_4 and T_3 irrigations were 54.8 and 31.7 %, respectively. The fruit yields of these species under various treatments in respective years have been shown in Table 4.

Performance of inter-crops

During first year of establishment of fruit trees, grain yield of *Pennisetum*, the first rainy season crop,

Table 4 Temporal changes in fruits yield (Mg ha^{-1}) of trees species

Fruit tree species	Treatments	2005*	2006*	2007	2008	2009	2010	2011
Carissa carandas	T_2	0.93 (75 %)	1.10 (90 %)	1.38	1.54	1.68	1.72	1.59
	T_3	0.84 (72 %)	0.92 (85 %)	1.13	1.42	1.46	1.54	1.62
	T_4	0.80 (70 %)	0.83 (76 %)	1.00	1.25	1.34	1.42	1.48
	Mean	0.86 (72 %)	0.95 (84 %)	1.17	1.39	1.49	1.56	1.56
Aegle marmelos	T_2	–	2.32 (60 %)	3.28	4.50	3.98	4.06	3.81
	T_3	–	1.85 (54 %)	2.24	3.60	3.36	3.85	3.58
	T_4	–	0.96 (48 %)	1.48	1.68	2.08	3.08	3.17
	Mean	–	1.71 (54 %)	2.33	3.26	3.14	3.66	3.52
Emblica officinalis	T_2	–	–	0.24	0.42	0.52	0.58	0.52
	T_3	–	–	0.19	0.31	0.38	0.46	0.49
	T_4	–	–	0.14	0.22	0.26	0.32	0.43
	Mean	–	–	0.19	0.32	0.39	0.45	0.48
LSD ($p = 0.05$) Species (A)	Species = 0.19; Irrigation water quality = 0.22 and Species × Irrigation water quality = 0.38							

* Frost year; values in parenthesis are percent of plants bearing fruits

decreased 13–25 % under irrigation treatments of T_3 and T_4 as compared to T_2. Only two irrigations of respective quality water as per treatment were applied during the growing season of the crop. There was no significant reduction in straw yield with application of any of the saline water irrigation treatments. As pointed out earlier, though this crop performed well but due to birds problem, this crop was replaced with *Cyamopsis* during rainy season of following consecutive years. In winter season of 2003, *Hordeum* performed well with mean grain and straw yield of 2.46 and 2.95 Mg ha^{-1}, respectively, with no significant difference in yield among treatments of saline water irrigation and fruit tree species or their combinations. The yield of *Cyamopsis* in subsequent years (from 2003 to 2006 and 2009 to 2011) decreased when irrigated with high salinity water or alternate use of low and high salinity water (Table 5).

The influence of canopy of the fruit trees was also observed on the yield of *Cyamopsis* crop. Reduction in yield of the companion crops was more when cultivated with *Aegle* because of larger canopy of the trees as compared to *Emblica* and *Carissa*. *Cyamopsis* crop failed due to heavy rains during rainy seasons in 2007 and 2008. Since 2008, *Hordeum* was replaced by *Brassica* crop during winter season. Like *Cyamopsis*, *Hordeum* and *Brassica* also showed reduction in yield due to higher salinity but to relatively lesser extent. The reduction in yield of these crops was relatively more under *Aegle* due to impact of larger canopy as compared to the other two fruit tree species.

Soil salinity development

Critical comparison of the soil salinity data suggested that there was salinity development in 0–1.2 m soil depth during summer after the harvest of winter crops. Increase in soil salinity was proportional to the irrigation water salinity used in agroforestry systems (Fig. 2).

Soil salinity was also affected by annual rainfall received. In the most of years of experimental period when rainfall was normal (~450 mm), salts accumulated with saline water irrigation in previous season were leached from the root zone soil profile (Fig. 3a). Such observations were recorded in all the years except during 2004 and 2006, when rainfall was below normal (321 and 340 mm, respectively). In all the evaluated fruit-based agroforestry systems under specified irrigation management options of this study, soil salinity build-up followed a negative linear relationship with annual rainfall (Fig. 3b), which can be represented by the following linear empirical function:

$$Y = -0.004X + 6.36; \quad R^2 = 0.45,$$

where Y represents salinity status in soil (ECe, dS m^{-1}) and X represents annual rainfall in cm.

Table 5 Yield (Mg ha^{-1}) of companion inter-crops grown with three species of fruit trees

Fruit trees	Treatment	Average (2003 to 2007)		Average (2008 to 2011)	
		*Hordeum vulgare**	*Cyamopsis tetragonoloba**	*Brassica juncea**	*Cyamopsis tetragonoloba**
Cc	T1	3.55 ± 0.31 (3.82 ± 0.23)	1.41 ± 0.27 (2.22 ± 0.36)	1.58 ± 0.14 (3.16 ± 0.29)	0.87 ± 0.05 (1.48 ± 0.12)
	T2	3.43 ± 0.34 (3.75 ± 0.29)	1.36 ± 0.27 (2.10 ± 0.32)	1.41 ± 0.09 (2.88 ± 0.16)	0.77 ± 0.02 (1.35 ± 0.06)
	T3	3.32 ± 0.33 (3.63 ± 0.18)	1.28 ± 0.28 (1.93 ± 0.30)	1.33 ± 0.07 (2.76 ± 0.13)	0.71 ± 0.02 (1.30 ± 0.04)
	T4	2.99 ± 0.25 (3.26 ± 0.15)	1.21 ± 0.28 (1.90 ± 0.35)	1.18 ± 0.08 (2.61 ± 0.10)	0.69 ± 0.02 (1.26 ± 0.02)
Eo	T1	3.80 ± 0.40 (4.14 ± 0.28)	1.47 ± 0.27 (2.46 ± 0.42)	1.77 ± 0.07 (3.64 ± 0.16)	0.96 ± 0.15 (1.55 ± 0.19)
	T2	3.56 ± 0.34 (3.89 ± 0.25)	1.38 ± 0.29 (2.27 ± 0.42)	1.73 ± 0.08 (3.61 ± 0.17)	0.83 ± 0.08 (1.43 ± 0.13)
	T3	3.29 ± 0.28 (3.42 ± 0.26)	1.27 ± 0.26 (2.09 ± 0.35)	1.66 ± 0.07 (3.48 ± 0.12)	0.78 ± 0.07 (1.39 ± 0.13)
	T4	3.04 ± 0.22 (3.16 ± 0.22)	1.16 ± 0.26 (1.87 ± 0.30)	1.58 ± 0.06 (3.36 ± 0.10)	0.73 ± 0.06 (1.33 ± 0.11)
Am	T1	3.55 ± 0.29 (3.87 ± 0.16)	1.38 ± 0.28 (2.31 ± 0.44)	1.53 ± 0.09 (3.08 ± 0.24)	0.94 ± 0.18 (1.53 ± 0.22)
	T2	3.27 ± 0.31 (3.50 ± 0.22)	1.30 ± 0.29 (2.14 ± 0.38)	1.26 ± 0.07 (2.68 ± 0.12)	0.78 ± 0.13 (1.41 ± 0.22)
	T3	3.08 ± 0.30 (3.30 ± 0.24)	1.25 ± 0.27 (1.99 ± 0.33)	1.21 ± 0.08 (2.55 ± 0.15)	0.72 ± 0.12 (1.34 ± 0.21)
	T4	2.78 ± 0.24 (2.99 ± 0.19)	1.14 ± 0.25 (1.79 ± 0.28)	1.11 ± 0.07 (2.33 ± 0.08)	0.66 ± 0.14 (1.26 ± 0.24)

Values in parenthesis represent straw yield with standard deviation

* Average yield and standard deviation

Cc Carissa carandas, *Eo Emblica officinalis*, *Am Aegle marmelos*, respectively

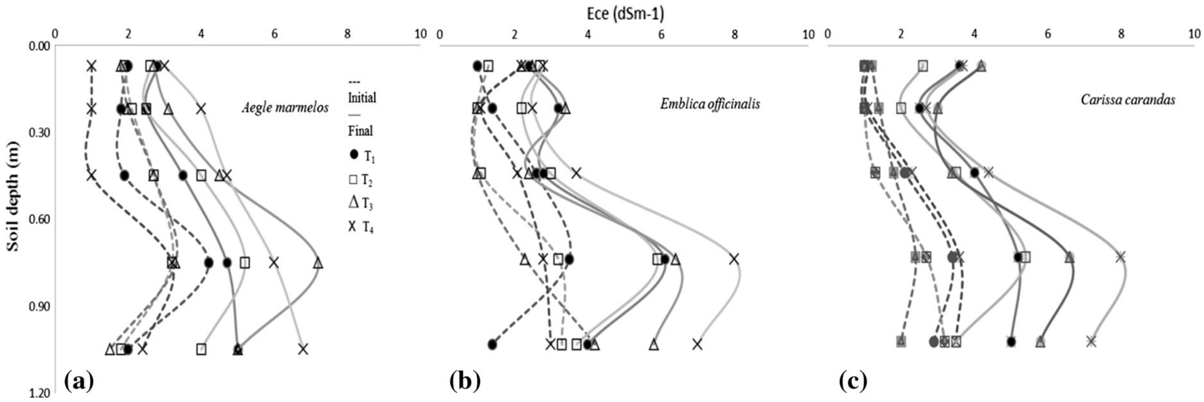

Fig. 2 Changes in salinity [ECe (dS m^{-1})] in 0 to 1.2 m soil profile under different quality water irrigation in *Aegle marmelos* (**a**), *Emblica officinalis* (**b**) and *Carissa carandas* (**c**)-based agroforestry systems

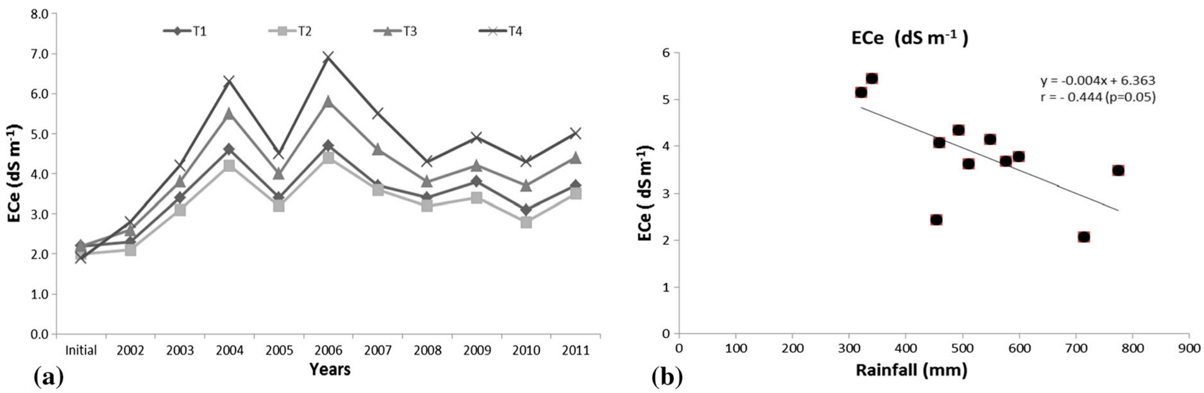

Fig. 3 **a** (*left*) Salinity variation in 1.2 m soil profile (average) during different years (2001–2011) of experimentation under different salinity water irrigation treatments, viz. crops irrigated with water of low salinity without trees (T_1); fruit trees and crops irrigated with water of low salinity (T_2); fruit trees and crops irrigated alternately with water of low and high salinity (T_3); and fruit trees and crops irrigated with water of high salinity (T_4). **b** (*right*) Relationship between soil salinity [ECe (dS m^{-1})] and annual rainfall (mm) during different years

This negative linear function suggests that under no rainfall conditions, the maximum soil salinity build-up will be 6.36 dS m^{-1}, and it is likely to decrease by 0.4 units with every 100 mm rainfall.

Discussion

As the tree saplings, including fruit trees are sensitive to water deficits during their establishment stage; plantation efforts in dry areas usually fail due to non-availability of fresh water and hesitation to use saline groundwater for irrigation. With saline irrigation, pre- and post-planting management strategies should tend to minimize the salinity build-up, thus lowering its negative impact on transplanted tree saplings (Armitage 1984; Gupta et al. 1995; Tomar et al. 1998). Earlier efforts in this direction (Tomar et al. 1994, 1998; Minhas et al. 1997a, b; Dagar et al. 2006, 2008) suggested that furrow planting proved advantageous in establishment of tree saplings in dry regions with continental monsoon type climate. Concentration of the most of the rain water received during monsoon period in the furrows helped in creation of niches of water and salt regimes favourable for the better establishment of saplings. Many tree evaluation studies (Jain et al. 1983; Chaturvedi 1984; Ahmad et al. 1985; Tomar et al. 2003b; Dagar et al. 2008) have also suggested that some salt-tolerant trees could be established with saline water irrigation, but the minimum input of salt into the soil needs to be ensured for better growth of trees. Even the saline groundwater resources in dry regions are also very limited and unstable for long-term sustainability of tree plantations that require regular irrigation. Tomar et al. (2003b) while evaluating tree species found some fruit trees such as *Feronia limonia* and *Ziziphus mauritiana* promising under saline irrigation. They established tree saplings by planting in the sill of furrows and irrigated with saline water (ECiw 8.5–10. dS m^{-1}) for initial 3 years. In present study, also fruit trees planted in the sill of furrows and irrigated with saline water proved successful in establishment of tree saplings. The success of this system was attributed to the reduced salt load and secondly to the significant leaching of the accumulated salts by seasonal but sufficient amount of rainwater into these furrows. Slow growth of the perennial woody species under dry land conditions with no productive utilization of the inter-row space results in low and much delayed (after long periods of >5 years) economic returns to the farmers.

Although *Cyamopsis* failed due to occurrence of very heavy rains of 167 and 123 mm in years 2007 and 2008, respectively, at the early stage of crop growth, but cultivation of lesser water-requiring salt-tolerant companion crops such as *Cyamopsis*, *Pennisetum*, *Hordeum* and *Brassica* in the inter-spaces between tree rows proved useful to offset the delay in economic returns to a good extent. Tomar et al. (2003a) and Qadar et al. (2008) studied and identified several suitable grass species for cultivation with saline irrigation. In addition to this, several medicinal and aromatic plant species suitable for dry land saline conditions have also been identified by Tomar and Minhas (2004 a, b), Patra and Singh (1995), Joy et al. (2006), Tomar et al. (2010) and Dagar et al. (2013). In most of these studies, high salinity water (10–12 dS m^{-1}) irrigation caused drastic reduction in crop yields. However, in some cases, the yields were comparable to that of irrigation using low salinity water (4–6 dS m^{-1}) when high salinity water used alternatively with low salinity water irrigation. This observation proved true for fruit trees as well as companion crops of *Brassica* and *Hordeum* in the present study also. Under saline conditions, irrigation with saline water is usually recommended to meet both water requirement of the crops and the leaching of extra salts present in rhizosphere to maintain a favourable salt balance in root zone (Shalhevet 1984; Rhoades et al. 1992). However, in dry areas, where sufficient water supplies are not available to meet leaching requirements, the increased frequency of irrigation rather adds to salinity in soil, thereby showing little impacts (Minhas 1996). Dagar et al. (2013) reported that lemon grass (*Cymbopogon flexuosus*) responded to irrigation water supplies (ECiw 8.6 dS m^{-1}) up to 0.8 times their evapo-transpiration needs, mainly due to the facts that salt leaching was occurring with monsoon rains and the major build-up occurred only during post-monsoon period. A similar observation of no appreciable build-up of salinity in soil profile was recorded even after nine years of experimentation in the present study. As evident from Fig. 2, despite application of saline water even of high salinity, there was no significant development of salinity, because the sufficient rainfall during monsoon season helped in leaching down the salts below root zone in the sandy loam soils. It seems that one normal rainfall (~450 mm) year in a cycle of 3–4 years is enough for leaching of the salts added with judiciously applied saline irrigations in evaluated fruit-based agroforestry systems in the present study.

These experimental evidences show the potential of cultivating the fruit trees along with low-water-requiring arable crops in dry regions utilizing available saline (ECiw 10 dS m^{-1}) groundwater for irrigation. Among the tree species, *Carissa*-based agroforestry system could be a successful option for areas where groundwater salinity is ~10 dSm^{-1}. However, considering the relatively higher demands of *Emblica* and *Aegle*, the agroforestry systems based on these two species are also viable options for moderately saline irrigation water situations.

Conclusions and recommendations

Fruit-based agroforestry systems have promised to improve livelihood in dry regions, where saline groundwater is the only source of irrigation. Although, the yields of *Cyamopsis* and *Brassica* reduced in the subsequent years with saline water and more so when intercropped with *Aegle, but Pennisetum* and *Hordeum*, and *Cyamopsis* and *Brassica* are promising intercropping system in *Carissa* followed by *Emblica*.

In the semi-arid regions receiving annual rainfall of ~450 mm, the saline groundwater (up to ECiw10 dS m^{-1}) can be exploited for irrigating these low-water-requiring fruit-based agroforestry systems. Provision of alternate irrigations of low salinity (ECiw 4–5 dS m^{-1}) water improved the performance of all component crops. 1 year of normal rainfall during a cycle of 3–4 years was found sufficient in leaching the salts added with saline irrigation.

References

Ahmad R, Khan D, Ismail S (1985) Growth of *Azadirachta indica* and *Melia azedarach* in coastal sand using highly saline water for irrigation. Pak J Botany 17(2):229–233

Armitage FB (1984) Irrigated forestry in arid and semi-arid lands: a synthesis. IDRC, Ottawa

Ayers RS, Westcot DW (1985) Water quality for agriculture. FAO Irrigation and Drainage Paper No. 29. Re.1, Rome, pp 173

Bouwer H (2002) Integrated water management for the 21st century: problems and solutions. J Irrig Drain Eng 28:193–202

Chaturvedi AN (1984) Firewood crops in areas of brackish water. Indian For 110(4):364–366

Dagar JC, Tomar OS, Yadav RK, Kumar Y, Bhagwan H, Tyagi NK (2006) Performance of some under-explored crops under saline irrigation in a semiarid climate in northwest India. Land Deg Dev 17:285–299

Dagar JC, Tomar OS, Minhas PS, Singh G, Jeet Ram (2008) Dry land biosaline agriculture—Hisar Experience. Tech Bull 6. CSSRI, Karnal, pp 28

Dagar JC, Tomar OS, Minhas PS, Mukesh Kumar (2013) Lemongrass (*Cymbopogon flexuosus*) productivity as affected by salinity of irrigation water, planting method and fertilizer doses on degraded calcareous soil in a semi-arid region of northwest India. Indian J Agric Sci 83(7):734–738

GoI (1998) India-A reference manual. Ministry of Information & Broadcasting, Government of India, Patiala House, New Delhi

Gupta RK, Tomar OS, Minhas PS (1995) Managing salt-affected soils and water for afforestation. Bull No. 7/95, Central Soil Salinity Research Institute, Karnal, pp 23

Jackson ML (1967) Soil chemical analysis. Asia Publishing House, New Delhi

Jain BL, Goyal RS, Muthana KD (1983) Performance of some tree species in relation to irrigation with saline water. Ann Arid Zone 22:233–238

Joy PP, Skaria BP, Mathew S, Mathew G, Joseph A (2006) Lemongrass: the fame of Cochin. Indian J Arecanut Spices Med Plants 8(2):55–64

Minhas PS (1996) Saline water management for irrigation in India. Agric Water Manag 30:1–24

Minhas PS, Singh YP, Tomar OS, Gupta RK, Gupta Raj K (1997a) Saline-water irrigation for the establishment of furrow-planted trees in north-west India. Agrofor Syst 35:177–186

Minhas PS, Singh YP, Tomar OS, Gupta RK, Gupta Raj K (1997b) Effect of saline irrigation and its schedules on growth, biomass production and water use by *Acacia nilotica* and *Dalbergia sissoo* in a highly calcareous soil. J Arid Environ 36:181–192

Ministry of Agriculture (2012) Agricultural statistics at a glance. Department of Agriculture and Cooperation, Directorate of Economics and Statistics, Ministry of Agriculture, Government of India, New Delhi

Morris J, Bickford R, Collopy J (1994) Tree and shrub performance and soil conditions in a plantation irrigated with saline ground water. Res. Report No. 357. Department of Conservation and Natural Resources, Victoria, pp 37

Patra DD, Singh DV (1995) Utilization of salt affected soils and saline/sodic irrigation water for cultivation of medicinal and aromatic plants. Curr Res Med Aromat Plants 17:378–381

Piper CS (1966) Soil and plant analysis. University of Adelaide, Australia

Qadar M, Oster JD, Schubert S, Noble AD, Saharawa KL (2007) Phytoremediation of sodic and saline-sodic soils. Adv Agron 96:197–247

Qadar M, Tubeileh A, Akhtar J, Labri A, Minhas PS, Khan MA (2008) Productivity enhancement of salt-affected environments through crop diversification. Land Deg Dev 19:429–453

Rhoades JD, Kandiah A, Mashali AM (1992) The use of saline water for crop production. FAO Irrigation & Drainage Paper 48, Food & Agriculture Organisation, Rome

Richards LA (1954) Diagnosis and improvement of saline and alkali soils. USDA, Washington DC

Rogers AL (1985) Foliar salt in *Eucalyptus* species. Aust For Res 15:9–16

Shalhevet J (1984) Management of irrigation with brackish water. In: Shaiberg I, Shalhevet J (eds) Soil salinity under irrigation. Springer Verlag, New York, pp 298–318

Tomar OS, Minhas PS (2004a) Relative performance of some aromatic grasses under saline irrigation. Indian J Agron 49(3):207–208

Tomar OS, Minhas PS (2004b) Performance of some medicinal plant species under saline irrigation. Indian J Agron 49(3):209–211

Tomar OS, Minhas PS, Gupta RK (1994) Potential for afforestation of waterlogged saline soils. In: Singh P, Pathak PS, Roy MM (eds) Agroforestry systems for degraded lands, vol 1. Oxford & IBH Pub Co Pv. Ltd, New Delhi, pp 111–120

Tomar OS, Gupta RK, Dagar JC (1998) Afforestation techniques and evaluation of different tree species for waterlogged saline soils in semi arid tropics. Arid Soil Res Rehabil 12(4):301–316

Tomar OS, Minhas PS, Sharma VK, Gupta RK (2003a) Response of nine forage grasses to saline irrigation and its schedules in a semi-arid climate of north-west India. J Arid Environ 55:533–544

Tomar OS, Minhas PS, Sharma VK, Singh YP, Gupta RK (2003b) Performance of 31 tree species and soil conditions in a plantation established with saline irrigation. For Ecol Manag 177:333–346

Tomar OS, Dagar JC, Minhas PS (2010) Evaluation of sowing methods, irrigation schedules, chemical fertilizer doses and varieties of *Plantago ovata* to rehabilitate degraded calcareous lands irrigated with saline water in dry regions of north-western India. Arid Land Res Manag 24:133–151