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Original Research Article

Effect of some Agricultural Practices on Field Performance of Jojoba (*Simmondsia Chinensis* L.) Seedlings in Semi-Arid Areas of Voi, Kenya

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Abstract

Low Jojoba (*Simmondsia chinensis* L.) seed production is partly due to inappropriate management practices. An experiment was conducted to select the best agricultural practices of Jojoba seedlings in semi-arid areas. The experiment was a randomized complete block design carried out for 10 months in 2013. Data was collected on survival %, plant height, root collar diameter, number of leaves and number of shoots. The results showed that a combination of manure, irrigation and micro catchment was the best agricultural practice since it gave significantly higher ($p \leq 0.05$) root collar diameter (17.1 mm) compared with the micro catchment (12.2 mm) alone which was the least. Similarly, micro catchment and irrigation combination showed the highest growth in height (86.4 cm) compared with the control (61.5 cm). The most ideal agricultural practice for field planted seedlings is a combination of manure, irrigation and micro catchment as opposed to single agricultural practices. This study recommends application of manure and supplemental watering during the early stages of Jojoba field establishment for improved growth.

Keywords: Agricultural practices, Jojoba seedlings, semi-arid areas

INTRODUCTION

Over 80% of Kenya is arid and semi arid land (ASAL) (KARI, 2009) with only a few crops being grown mainly for subsistence purposes. These areas lack cash crops which are drought tolerant and irrigation systems are poorly developed. They experience frequent drought leading to crop failure hence overdependence on food relief (Barrow, 1996).

Serious mitigation programmes are needed to combat global climate change which is anticipated to have far reaching effects in many parts of the world including Kenya as outlined by Ottichilo *et al*. (1991). Priority is being given to high yielding genotypes which can survive unexpected environmental changes, particularly in regions of water deficits (Akinci and Losel, 2012). In recent years, there has been considerable interest in using ASALs more productively by promoting crops which can tolerate these conditions such as *Jatropha curcas* (Ngethe, 2007) and Jojoba (*Simmondsia chinensis)* (Thagana *et al*., 2004). These are multipurpose crops, and have a potential use for rehabilitation as well as provision of income to the poor communities.

Jojoba is a high value desert shrub which is a dioeciously species with male and female plants in the ratio 1:1 in the field when raised from seed. A Jojoba stand can be in production for 100-200 years depending on management (Martin, 1983) and has a deep rooting habit (Forster and Wright, 2002). Jojoba produces nuts with 45-55% of its weight as oil. The oil from Jojoba is similar to that obtained from Sperm Whale which is threatened with extinction (Hogan and Bemis, 1983). The oil is used in cosmetics, lubricant industry, pharmaceuticals, electronics and computer industries

(Undersander *et al*., 1990; Amarger and Mercier, 1996; Ward, 2003).

Jojoba is the sole species of the family *Simmondsiaceae* and is a native shrub of Sonoran desert of Arizona, Southern California and North Western Mexico. It is grown in Israel, Argentina, Brazil, India, Egypt, Saudi Arabia, Australia, South Africa, Peru, Chile and Iran (Undersander *et al*., 1990).

Jojoba is drought tolerant adapted to hot, dry climate (Ash *et al*., 2005) and offers promise for agriculture in harsh environments (Ahmad, 2001; Al-Hamamre, 2013) where many conventional crops cannot survive, yet it requires water for the first 2 to 3 years for proper root establishment (Forster and Wright, 2002). Similarly, for sustained high yields, watering is essential in areas with low rainfall, especially in desert areas with less than 350 mm annually. Irrigation is quite advanced in Jojoba production especially in Israel, America and India (NRC, 2002; Pinoyfarmer, 2007).

A lot has been done on irrigation (NRC 2002) as a management tool which is quite an expensive option but its use for Jojoba is justified by the high returns. However, there is a great need to explore possibilities of other cheaper management alternatives in order to improve the overall performance of Jojoba plantations for resource poor farmers who are the majority in ASALs. There is enormous potential of harnessing excessive runoff cheaply through creation of micro-catchments (Critchley and Siegert, 1991; Rowland, 1993; Mati, 2005; Itabari *et al*., 2011) for use by the crop for a longer period. There is, also, easy availability of manure from the cattle bomas which are in close proximity, since livestock is the major enterprise in ASALs. According to Harris and Yusuf (2001), inorganic fertilizers have low adoption in ASALs of sub aharan Africa since they are expensive (Mehdizadeh *et al*., 2013), hence manures are the most effective ways of improving soil fertility and maintaining soil structure (Kihanda *et al*., 2006).

Jojoba has been used to combat and prevent desertification in the Thar desert in India (Alsharhan *et al*., 2003) and Negev desert in Israel (Benzioni, 1997). Jojoba needs little water for survival (a third or less of the moisture required by crops like citrus or cotton), however, economic consideration dictate that irrigation is essential for a healthy, profitable crop in many dry areas (Ayerza, 1993; CJP, 2007).

Poor management of the existing Jojoba bushes has led to low production of seeds (0.5-2 kg/bush) through severe abortion of flowers and pods. This is mainly through competition for nutrients, water and space (Weber and Stoney, 1986; Rowland, 1993). Agronomical requirements of Jojoba are still under experimentation especially in the tropical environment where little has been done (NRC, 2002).

According to Martin (1988), Jojoba is highly valued in the international market where it sells at US$ 10-50 per litre of oil. The seed production per bush is 2-3 kg per year which translates to 2 to 3 metric tonnes per hectare (ha). The amount of Jojoba oil produced per ha is equated with the quantity produced by 124 whales (Ward, 2003). The seed yield can reach 4-5 kg/bush with improved selection and management (CJP 2007). Jojoba has come at a time when there are dwindling natural resources and increased concern for the environment (Tremper, 1996).

Currently, there is low production in the existing Jojoba plantations in Kenya partly due to inappropriate agricultural practices, hence the need for this study. Management of young field planted Jojoba seedlings using appropriate cultural techniques will help to improve their early growth and successive seed yield for better economic benefits, hence giving the local people a reliable cash crop in the ASALs. The results of the study will be useful to farmers, researchers, environmentalists and policy makers. The study hypothesized that appropriate agricultural practices can help to improve early growth of Jojoba bushes.

The objective of this investigation was to select the most appropriate agricultural practices for establishing field planted Jojoba seedlings in semi arid areas of Kenya.

MATERIALS AND METHODS

Site description

The research was conducted at Wildlife Works Ltd, Maungu, Voi, where Jojoba bushes have been established. It is located 20 km east of Voi urban centre, Voi District, Taita Taveta County, Coast Province of Kenya, at an altitude of 892 m above the sea level. It lies between latitudes 3^0 23'60'' to 3^0 24' 26'' S and Longitudes 37^0 40' 60'' to 38^0 35' 25'' E.

The study site lies in the semi arid savannah which receives an average annual rainfall of 458 mm with a bimodal pattern of distribution (Figure 1). Long rains are received between March and May while the short rains are received between November and December. Temperatures range from 16-37^{0}C with an average of 25^{0}C with moderate relative humidity of 59% and annual number of rainy days being 42.7 (TTDP, 2008).

Soils are moderately fertile with sandy loam and gravel texture and pH of 5-7 (Jaetzold and Schmidt, 1983; Thagana *et al*., 2003). Sandy loam soil was characterized by Njeru *et al*. (2011) in a semi arid environment of Mbeere south District, Kenya to comprises of 60% sand, 23% silt and 17% clay and fertility of 0.15% N, 130.5 and 410 ppm (P and K respectively) and 0.93% C.

Experimental design and sampling techniques

The experiment was laid down in a randomized complete

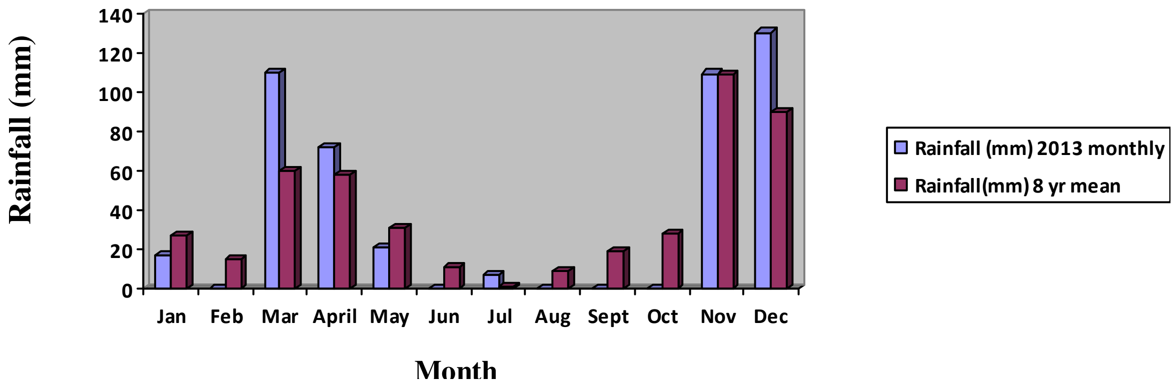

Figure 1. Monthly rainfall distribution during the study period (Year 2013) and monthly mean for 8 years

block design (RCBD) with 8 treatments replicated 3 times. The treatments were constituted by agricultural practices which were as follows: manure; micro-catchment; irrigation; manure and micro-catchment; manure and irrigation; micro-catchment and irrigation; manure, micro-catchment and irrigation and control. All the treatments (agricultural practices) were independently and randomly allocated in the field and each treatment consisted of 4 seedlings.

The experiment was carried out between mid-January and mid-November 2013. The experimental site was 0.05 ha and it was cleared and ploughed 3 months before planting. The seedlings were raised in the nursery for 7 months before transplanting them to the field. Field spacing was 1 x 4 m according to recommendations by Yermanos (1979) and CJP (2007), while the planting hole was 60 x 30 cm (depth and width respectively). There is a wide range of hole sizes depending on the crop and site, but USAID (2006) recommended 75-90 cm deep x 50 cm wide for Jojoba in Egypt. The micro-catchments were 3 x 1 m (length and width respectively) on 8% slope depending on the spacing. Micro-catchments are water harvesting structures which involve modifying the ground surface by construction of bunds in order to direct the runoff to the bottom of the plant (Mati, 2005).

Irrigation water was applied only during dry season (mid-January to mid-March and June to October) at a rate of 10 litres per seedling per week (equivalent to 320 litres/seedling/year). Irrigation water application has been reported to range between 2,000 to 4,000 litres/plant/year for mature Jojoba plantations (CJP, 2007). However, at planting, enough water was applied equally to all seedlings at a rate of 10 litres after 2 days and was observed for the first 2 months before the onset of rains. On the other hand, 4 kg per hole (equivalent to 10 t/ha) of cattle boma manure was applied at planting according to recommendations by Kihanda (1996). According to Mureithi *et al*. (1994) most of the boma manures are highly variable with N level ranging from 0.46-1.98%. Nutrients from manure are released within 4 to 8 weeks after application (Andrews and Foster, 2007).

Data collection

Three plants were randomly sampled per treatment per replicate and data was collected over time (at intervals of 3 months) at 1, 4, 7 and 10 months of the seedling growth. The data collection interval was chosen depending on the growth rate of the seedlings and the period of the trial. The following variables were scored: plant height, root collar diameter, number of leaves and number of shoots. Data on survival percentage was based on complete enumeration of the surviving seedlings in relation to the initial planting.

Data analysis

One way analysis of variance (ANOVA) model (a randomized complete block design) was used to test differences between treatment means using SAS statistical package (SAS, 1996) while the significantly different treatment means were separated by F ratio using Least Significance Difference (LSD) at $p \leq 0.05$ (Gomez and Gomez, 1984).

RESULTS

One month old Jojoba seedlings in the field (Table 1) did not show any significant difference among treatments in all the variables measured except for root collar diameter. The highest root collar diameter (4.8 mm) was shown by the control which was significantly different ($p \leq 0.05$) in relation to manure, micro catchment and irrigation combination (3.4 mm).

At 4 months of age, agricultural practices did not show any significant difference in all the variables measured (Table 2). However, the highest survival (100%) was shown by irrigation alone, manure and micro catchment combination, manure and irrigation combination as well as the control.

The highest height (43.6 cm) and root collar diameter

Table 1. Effect of agricultural practices on the survival and growth of 1 month old Jojoba seedlings

Agricultural practice	Survival%	Height (cm)	Root collar diameter (mm)	Number of leaves	Number of shoots
Manure	100.0a	32.2a	4.4a	38.6a	3.4a
Microcatchment	89.0a	31.5a	4.0ab	41.9a	4.2a
Irrigation	100.0a	35.5a	4.2ab	35.8a	2.8a
Manure and Microcatchment	100.0a	31.9a	4.3ab	37.7a	3.3a
Manure and Irrigation	100.0a	31.9a	4.4a	34.8a	2.6a
Microcatchment and Irrigation	89.0a	32.3a	4.0ab	37.9a	3.4a
Manure, Microcatchment and Irrigation	100.0a	30.4a	3.4b	30.8a	2.4a
Control	100.0a	33.4a	4.8a	44.3a	3.4a
CV	10.1	13.2	12.2	24.2	56.2
LSD	17.3	7.5	0.9	16	3.2

Means with the same letter(s) in each column are not significantly different to each other using LSD at $p \leq 0.05$

Table 2. Effect of agricultural practices on the survival and growth of 4 months old Jojoba seedlings

Agricultural practice	Survival%	Height (cm)	Root collar diameter (mm)	Number of leaves	Number of shoots
Manure	88.9	39.7	5.2	90.6	6.5
Microcatchment	88.9	34.5	5.0	95.5	6.2
Irrigation	100.0	39.9	5.5	81.6	6.3
Manure and Microcatchment	100.0	34.1	4.4	89.1	7.6
Manure and Irrigation	100.0	43.0	5.8	92.2	6.2
Microcatchment and Irrigation	77.8	42.2	5.2	100.2	7.3
Manure, Microcatchment and Irrigation	66.7	43.6	6.4	79.7	7.6
Control	100.0	37.6	4.8	113.7	7.8
CV	23.5	15.4	25.9	29.6	32.6
LSD	37.1	10.6	2.4	48.8	4.4
$p \leq 0.05$	NS	NS	NS	NS	NS

NS= No significant difference among the means in each column

(6.4 mm) were shown by manure, micro catchment and irrigation combination which were higher by 16 and 33.3% respectively relative to the control. The best growth performance was shown by manure, micro catchment and irrigation combination whereas the least was manure and micro catchment combination.

Seven months old Jojoba seedlings (Table 3) showed significant differences ($p \leq 0.05$) among treatments in height and root collar diameter variables. The tallest height (71.5 cm) was shown by micro catchment and irrigation combination which was significantly higher ($p \leq 0.05$) relative to micro catchment alone (46.3 cm), manure and micro catchment combination (50.4 cm), manure, micro catchment and irrigation combination (47.3 cm) as well as the control (48 cm).

On the other hand, the largest root collar diameter (26.8 mm) was shown by manure alone which was significantly different ($p \leq 0.05$) relative to micro catchment alone (9.8 mm), manure and micro catchment combination (9.1 mm) as well as the control (10.2 mm). The highest height and root collar diameter were significantly higher by 49 and 163% respectively in relation to the control.

The best agricultural practices were manure alone as well as micro catchment and irrigation combination whereas the lowest were micro catchment alone as well as manure and micro catchment combination.

The 10 months old seedlings showed significant differences ($p \leq 0.05$) in height, root collar diameter and number of leaves (Table 4). The highest height (86.4 cm) was shown by micro catchment and irrigation combination which was significantly higher than all the other agricultural practices with the exception of manure and irrigation combination (69.9 cm) as well as manure, micro catchment and irrigation combination (71.6 cm).

On the other hand, the biggest root collar diameter (17.1 mm) was shown by manure, micro catchment and irrigation combination which were significantly higher ($p \leq 0.05$) than micro catchment alone (12.2 mm). The latter was also significantly lower than manure and irrigation combination (16.5 mm).

Similarly, the highest number of leaves (462.7) was shown by manure and irrigation combination which was significantly higher ($p \leq 0.05$) than micro catchment alone

Table 3. Effect of agricultural practices on the survival and growth of 7 months old Jojoba seedlings

Agricultural practice	Survival %	Height (cm)	Root collar diameter (mm)	Number of leaves	Number of shoots
Manure	89.0a	54.1ab	26.8a	154.0a	20.7a
Microcatchment	89.0a	46.3b	9.8b	175.0a	17.6a
Irrigation	100.0a	54.8ab	10.8ab	221.3a	17.0a
Manure and Microcatchment	100.0a	50.4b	9.1b	193.7a	23.2a
Manure and Irrigation	100.0a	55.0ab	10.6ab	250.7a	24.1a
Microcatchment and Irrigation	77.7a	71.5a	12.0ab	232.3a	23.0a
Manure, Microcatchment and Irrigation	66.8a	47.3b	11.1ab	147.7a	18.7a
Control	100.0a	48.0b	10.2b	198.0a	24.3a
CV	23.5	19.5	74	35.7	39.6
LSD	37.1	18.3	16.3	123	14.6

Means with the same letter(s) in each column are not significantly different to each other using LSD at $p \leq 0.05$

Table 4. Effect of agricultural practices on the survival and growth of 10 months old Jojoba seedlings

Agricultural practice	Survival%	Height (cm)	Root collar diameter (mm)	Number of leaves	Number of shoots
Manure	89.0a	64.8b	15.0ab	268.9ab	30.2a
Microcatchment	89.0a	61.4b	12.2b	246.5b	24.0a
Irrigation	100.0a	62.2b	15.0ab	199.4b	29.1a
Manure and Microcatchment	100.0a	60.7b	14.7ab	282.8a	33.7a
Manure and Irrigation	100.0a	69.9ab	16.5a	462.7a	43.3a
Microcatchment and Irrigation	77.7a	86.4a	15.4ab	315.7ab	47.7a
Manure, Microcatchment and Irrigation	66.7a	71.6ab	17.1a	328.7ab	43.7a
Control	100.0a	61.5b	16.2ab	385.0ab	39.0a
CV	23.5	17.7	15.3	38.1	52.5
LSD	37.2	20.9	4.1	199.2	33.4

Means with the same letter(s) in each column are not significantly different to each other using LSD at $P \leq 0.05$

(246.5) as well as irrigation alone (199.4). The latter two treatments were also significantly lower than manure and micro catchment combination (282.8). The highest height was significantly higher by 37.6% relative to the control, whereas the highest root collar diameter, number of leaves and shoots were higher in relation to the control by 5.6%, 20.2% and 12.1% respectively.

The best growth performance was shown by manure, micro catchment and irrigation combination whereas the lowest were micro catchment alone as well as irrigation alone.

DISCUSSION

The results of this study are consistent with the findings of other authors who reported that manure or compost application can improve N and P levels as well as soil structure and moisture retention leading to increased crop production for one year (Murwira *et al*., 1995; Nelson, 2001) and influenced soil properties for several years (Mugwira, 1979; Mortimore *et al*., 1995; Eghball *et al*., 2002; Eghball *et al*., 2004; Kihanda *et al*., 2006). Organic matter (OM) increase by 1% has been reported by Sullivan (2002) to raise water storage by 120 m^3/ha. This reduces the severity of drought and also the need for irrigation. Manure is necessary to provide nutrients and improve soil structure for fast growing Jojoba seedlings, since the pots used to raise seedlings were not large enough to provide further nutrients for growth in the field considering the fast growth of roots at 2.5 cm per day according to CJP (2007).

Feldman (1982) reported that early growth of transplanted Jojoba seedlings in the field was significantly greater for inorganic fertilized plants in the nursery. Benzioni and Nerd (1985) observed the increase in Jojoba growth and yield due to irrigation as well as large additional effect through NPK fertilizer application. CJP (2007) recommended application of NPK to Jojoba at a rate of 75, 37.5 and 75 kg for NPK/ha/yr respectively, whereas Pinoyfarmer (2007) reported response of Jojoba to N and Zn and but recommends little fertilization. Presence of N has been reported by Ali *et al*. (2013) to result to more vegetative growth compared to flowering growth.

According to Undersander *et al*. (2009) and Hussein *et al*. (2013), fertilization has limited impact on Jojoba productivity although foliar application of K and Zn help the plants to tolerate drought (Aown *et al*., 2012) through accumulation of abscisic acid (ABA) (Ferriere *et al*.,

1989) leading to stomatal closure (Ali and Mahmoud, 2013). The low requirement for nutrients especially for mature bushes can partially be due to deep rooted nature of Jojoba (Osman and AboHassan, 1998) which enables it to bring back to the surface the leached soil nutrients through senescent leaves and prunings. Heterogeneous nature of Jojoba population (Ayerza, 1993; Inoti *et al*., 2015) might have contributed to the lack of positive continuous response to NPK fertilizer application as earlier observed by Nerd and Benzioni (1988) and Al-Soqeer (2010).

The low performance in growth of Jojoba seedlings through use of micro catchment alone can be due to inadequate infiltration rate due to surface sealing and failure to dig out the soil around the tree after each runoff event (Critchley and Siegert, 1991). McGarry *et al*. (2007) observed that tillage leads to pulverization of soil particles washed away through runoff and later resulting in surface sealing by blocking the soil micropores. Soil surface disturbance through tillage causes moisture loss. Every soil disturbance on the top 5 cm depth causes soil moisture loss of 6 mm although this varies with texture, percent OM and amount of surface residue (Al-Kaisi *et al*., 2000).

When moisture is very limited, soils tend to have massive structure and any disturbance could damage newly formed root systems. Under dry conditions, it is recommended to scrap small weeds on the surface without disturbing the soil too deeply (Al-Kaisi *et al*., 2000). According to Ramos and Martinez-Casasnovas (2007) and Mussery *et al.* (2013), highly disturbed soils had lower soil moisture than low disturbed soils and accompanied by less infiltration, more sealing and soil erosion. After a long dry spell, highly disturbed soils dry faster.

However, Schiffner (2012) stated that soil moisture storage efficiencies of 40-60% in ASALs are achieved when tillage is minimized or eliminated. Benites and Castellanos (2003) reported that minimal soil disturbance leads to increase in soil moisture resulting in increased yields if nutrients are available. Low moisture level in the soil leads to depression of water availability and also nutrient absorption (Hussein and El-Dewiny, 2011). Albedo or soil spectral reflectance decreases with increase in soil organic matter (SOM), surface roughness (Matthias *et al*., 2000) and soil moisture (Vinogradov, 1983).

Roots absorb more water when soil temperature increases up to a certain maximum which depends on the crop. High temperatures can also restrict water absorption leading to adverse effect on seedling establishment, crop growth and also microbial population development (McGarry *et al*., 2007). Vegetative growth in Jojoba varied with drought stress (Malende, 1989; Osman and AboHassam, 1998). Drought stress has been reported by Akinci and Losel (2010) to lead to reduced height and number of leaves in cucurbitaceae family.

In ASALs, most crops will require watering in areas with rainfall below 250 mm per year. Jojoba plants failed to flower below 109 mm of rain per year. In the natural range, Jojoba can grow between 80-460 mm rainfall/year (Gentry, 1958; Pinoyfarmer, 2007). However, supplementary irrigation can maximize and sustain production in Jojoba where annual rainfall is less than 640 mm (Pinoyfarmer, 2007). According to El-Bassam (2010), Jojoba requires 750 mm/year for adequate growth which is critical for early stages, flowering and seeding.

Irrigation ensures good crop establishment, shortens time to maturity, doubles the number of roots, increases number of buds, allows more dense plantings and increases time of photosynthesis (Pinoyfarmer, 2007). Over 80% of the lateral roots of Jojoba are found within the top 1 m soil depth (Pinoyfarmer, 2007). Water for effective irrigation is about one third of that lost through evaporation in ASALs and NPK fertilizers are added in the water (Gentry, 1958).

This study shows that combinations of agricultural practices are superior relative to single applications. These results are consistent with findings of on-farm trials in Arusha and Arumeru districts in Tanzania by Rockstrom (1997) and semi-arid areas of Kenya by Kihanda *et al*. (2006) who reported that combined water and fertility management can greatly improve crop yields as opposed to either of the two. Rapid seedling establishment is an important requirement for successful crop farming in ASALs, since it helps the plants to escape from drought (Balkan, 2012).

Incorporation of animal manure is necessary to combat decline in soil fertility and structure (Rowland, 1993; Kihanda and Gichuru, 1999) and the recommended rate is 5-10 t/ha (Kihanda, 1996). According to Andrews and Foster (2007), manures release 40-70% nutrients within 4-8 weeks after application. However, in drylands, the quantity of manure applied is restricted due to burning of the crop when insufficient moisture is available at the time of application (FAO, 2004). These observations are consistent with the present study since single manure applications are discouraged. This burning effect was observed in mature bushes outside the experimental plot in this study. Farmers wait until onset of rains to apply manure in ASALs.

This study is consistent with a study by Condron *et al*. (2014) who reported that irrigation of grazed pasture significantly increases plant production but had less effect on soil organic carbon (SOC). Securing a water source during dry spells through irrigation can be an incentive needed for investment on improved soil moisture, which in turn can result in progressively increasing yields and profits (Cooper *et al*., 1987; Rowland and Whiteman, 1993; Figueres *et al*., 2003; Itabari *et al*., 2011). There was also accelerated decomposition of Organic Carbon (OC) resulting from higher soil moisture maintained throughout the growing season. Depletion of SOM was reported by Du Preez *et al*. (2010) to be relatively higher in irrigated compared to non-irrigated in drylands. According to Mor-Mussery *et al*. (2014), severe depletion of SOM is a leading cause for long term soil degradation in drylands with the sparse annual vegetation incapable of restoring the SOM pool.

The findings of Sullivan (2002) and FAO (2005) reported yield increase of 300% compared with yields without runoff harvesting in drylands. NAS (1974) observed the beneficial effects of 32 m^2 micro-catchments for growing pasture shrubs in Negev, Israel and reported maximum response which increased the yields of shrubs 15 times those of untreated land. Water harvesting has also been equated to irrigation since it gives similar yields.

Weber and Stoney (1986) mentioned the need to have wide spacing in marginal areas in order to have sufficient area for micro-catchment. Water harvesting can improve production and carrying capacity of drylands. Other contrasting studies have reported that micro catchments have been used to establish trees successfully in Northern Kenya, west of Lake Turkana (Koohafkan and Stewart, 2008). Trees such as *Prosopis*, sorghum and grasses have benefited from this technique in marginal areas. Micro-catchments have been used successfully in Near East, Africa and America and especially in the Negev desert in Israel. This technique is more widely applicable than irrigation and may have useful environmental benefits as regards erosion control. It offers more hope for increasing production in ASALs for which irrigation is not a viable option due to capital limitations (Critchley and Siegert, 1991; Mati, 2005).

Only 15-30% of rainfall is actually used in productive food making, while 70-85% of rainfall in water-scarce farming is lost through runoff, evaporation and drainage which mean that there is a high volume of water that can be tapped for use for productive purposes (Rockstrom, 1997). The present study was not able to tap this runoff potential due to poor distribution of rainfall hence rendering micro catchments to be ineffective. This study will help the farmers, extension workers and policy makers in scaling up Jojoba production in arid and semi-arid areas.

CONCLUSION AND RECOMMENDATIONS

Manure, micro catchment and irrigation combinations were superior compared to single application in early growth of field planted Jojoba seedlings. This study reveals that Jojoba can be grown successfully using the available resources in the ASALs.

The study recommends the use of manure, micro catchment and irrigation combinations in early establishment of Jojoba in the ASALs. Further investigation should be done on the effect of agricultural practice on field planted seedlings in a normal year with adequate rainfall (450-600 mm) and properly distributed in order to ascertain the low performance of micro catchments noted in this study.

The possibility of wider spacing in the field as opposed to the present 4 x 1 m in order to give a larger surface area for micro catchment should be explored. Research on agricultural practices in the field planted seedlings should be conducted over a longer period of about 3-4 years in order to realize their effect on yields. There is also urgent need for research in the amount of water used for irrigation technology to supplement rainfall.

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