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Effectiveness of water-saving techniques on growth performance of Mango (*Mangifera Indica* L.) Seedlings in Mihitsab-Azmati Watershed, Rama Area, Northern Ethiopia

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ABSTRACT

Even though mango productivity in Ethiopia is low due to moisture stress, there is no report on how such constraint could alleviate using Cocoon water-saving technology. Cocoon is small water reservoir technology which uses for plant growth in dry season. The objectives of this study were to introduce and evaluate effectiveness of water-saving techniques on mango seedlings survival and growth in Mihitsab-Azmati watershed, northern Ethiopia. In this experiment, five treatments of water-saving techniques with mango seedlings were evaluated. These were: Cocoon sprayed by tricel (T1), Cocoon painted by used engine oil (T2), Cocoon without tricel and oil (T3), manually irrigated seedlings (T4) and mango seedlings planted during rainy season (T5). The survival and growth performance of mango seedlings were recorded at six months and one-year after transplanting. Data on plant survival, height, number of leaves per plant, shoot length, stem diameter and crown width were subjected to analysis of variance and *t*-test. There were significant differences in the treatment effects on mango seedlings transplanted survival, plant height, number of leaves per plant, shoot length, stem diameter and crown width measured at six months and one-year after transplanting. The lowest survival rate (20 %) was found during both data collection time in T5. Six months after transplanting, the highest growth parameters were measured from T1 whereas the lowest was from T5. However, one-year after transplanting, the highest growth parameters were measured from T3. Plant heights increments between the two measurement periods for T3, T2, T1, T4 and T5 were 45.1, 38.5, 24.8, 9.8 and 7.0 cm, respectively; indicating that T3 performed better than the other treatments. The *t*-test on mean differences between the same growth parameter measured at 12 and six months after transplanting also showed significant differences. The Cocoon water-saving technology was superior in improving mango seedlings survival and growth in the study area. This study generalized that Cocoon seems promising, sustainable and highly scalable with mango seedlings at large-scale in the study area conditions. However, this technology should not be assumed to perform uniformly well in all environmental conditions and with all tree species before demonstrated on a pilot study.

1. Introduction

Mango (*Mangifera indica L.*) belongs to the plant family Anacardiaceae in which it is one of the 73 species in the Mangifera genus that are originated in South-East Asia (Morton, 1987; Kosterman and Bompard, 1993; Stangeland, 2011; Ahmed and Mohamed, 2015; Wei et al., 2017; Neguse et al., 2019). Mango is one of the most widely grown fruit crops in the tropical and subtropical regions including in arid and semiarid areas in the presence of appropriate water management practices. In developing countries where food and nutritional insecurity are still reported as big challenges, mango is considered as the king of the fruits because of its excellent flavor, delicious taste and high nutritive values (Hill, 1952; Bally et al., 2009; Ullah et al., 2010; Vasugi et al., 2012; Rekhapriyadharshini, 2015; Neguse et al., 2019). As a result, mango is one of the most widely grown fruit crops cultivated next to banana in terms of economic importance in Ethiopia. Moreover, within the past

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one decade in Ethiopia, both area coverage and production of mango has been increased by 208 and 247 %, respectively. Under such expansion of mango trees, water deficit has been reported as a crucial environmental stress on agricultural productivity and limits the economical development (Dessalegn et al., 2014; Fita, 2014; Wei et al., 2017; Neguse et al., 2019). This indicates the need for water-saving technologies in order to reduce the effect of water deficit on agricultural production such as mango farms. In the context of this paper ``water-saving" technologies are described as tools that may help increase survival and growth of planted seedlings while reducing the need for manual watering while speeding the ecological restoration process (Kulkarni, Jaramillo, 2015; Jaramillo et al., 2015a, b; Tapia et al., 2019).

Regardless of the mango crop potential to contribute towards income improvement and nutritional status in Ethiopia, the national average production yield is 7 ton ha^{-1}. The productivity in the country is very low as compared to the crop potential production (20−30 ton ha^{-1}) (Griesbach, 2003; Tiwari and Baghel, 2014; Neguse et al., 2019). The low productivity of mango crop in Ethiopia is governed by various factors (e.g., water deficit, environmental variables, management factors or a combination of such variables). However, there is no report that addresses environmental and management factors that constrained mango growth at the early stage, specifically using water-saving techniques such as Cocoon in degraded areas with arid and semiarid environmental conditions in Ethiopia. Even at global scale, there are very few published reports that tested for the contribution of the Cocoon water-saving technology on survival and growth performance of mango trees seedlings planted on degraded soils and areas with critical water shortage (e.g., Kulkarni, 2011; Jaramillo, 2015; Tapia et al., 2019). The Cocoon is a small water reservoir in which water is stored for plant growth in the dry season and thereby eliminating the need for irrigation (Land Life Company (LLC), 2015, 2016).

Water deficit (moisture stress) is the most persistent environmental stress on fruit crops such as mango growth and productivity in which this limits its contribution to improve nutritional status and economic development of a given society. Population growth coupled with irrigation land use expansion including mango plantation increased pressure on water availability dramatically now and in the future (Hussen and Yimer, 2013; Wei et al., 2017; Neguse et al., 2019; Comparini et al., 2020; Jaramillo et al., 2015). In addition, rainfall is characterized by high spatial and temporal variability coupled with severe soil degradation due to soil erosion and nutrient depletion, resulted in declined agricultural productivity (Tamene, 2005; Tesfahunegn et al., 2014; Tesfahunegn, 2015; Tesfahunegn et al., 2016; Tesfahunegn, 2019; GhassemiSahebi et al., 2020; Tesfahunegn and Gebru, 2020). Such conditions challenge the processes how to meet the increasing food demand by the community as the livelihoods of landless youth depend on degraded natural resource base on the steep slope topography. This and the worsening climatic conditions aggravate water scarcity problem in arid and semiarid areas of Ethiopia. It is important to apply the right agricultural practices and agricultural water management systems in order to increase agricultural water productivity of fruit crops (Möller and Assouline, 2007; Hussen and Yimer, 2013; Wei et al., 2017; Neguse et al., 2019).

Many watershed management practices (soil and water conservation, water harvesting, and plantation) have been implemented for a long time in Tigray region, northern Ethiopia. However, some promising results on improving income, food security, water resources for irrigation, and vegetation coverage have been reported in this region (Hussen and Yimer, 2013; Tesfahunegn and Gebru, 2020). Since 70 % of the land feature of the Tigray region in northern Ethiopia is undulating topography and rainfall distribution of the region is mainly for two months (July and August) with higher runoff and soil loss potential, the remaining long dry months are so difficult for the survival of tree seedlings plantation (Tamene, 2005; Tesfahunegn et al., 2014, 2016; Tesfahunegn and Gebru, 2020). In such conditions, even though millions of seedlings have been planted every year in the past many decades, there are conditions almost all of the seedlings planted died that resulted in poor survival rate and poor growth performance in the northern Ethiopia conditions (Hussen and Yimer, 2013; Abdullah, 2017; Wei et al., 2017; Neguse et al., 2019). However, there is interesting water-saving technology such as Cocoon which has been successfully implemented globally in the projects across 15 countries (in Africa only in Kenya and South Africa). Results from such Cocoon projects globally confirmed seedlings plantation survival rates of 80–95 % and significant savings on labor costs and water use in comparison to the traditional land restoration practices. Reports from such projects have suggested that the Cocoon water-saving technology could provide a better opportunity for improving seedling survival rate and other plant growth parameters in the arid and semiarid climatic conditions even on areas affiliated with severely degraded land (Land Life Company (LLC), 2015; Abdullah, 2017). Cocoon is the only biodegradable water-saving technology designed to increase survival and growth of planted seedlings, reducing the need for manual and regular irrigation and enhances land restoration process such as improving vegetation cover and soil systems (Lampayan et al., 2004; Land Life Company (LLC), 2015, 2016; Abdullah, 2017; Wei et al., 2017; Tapia et al., 2019).

The Cocoon function by holding water in its storage that surrounds the young plant and feed water to the soil at a slow but constant rate through the capillary action via a short length of rope that connects the water in the Cocoon to the soil (Land Life Company (LLC), 2015). Cocoon is designed to restore dry and deforested land where there is no affordable or maintainable substitute as this enables trees to be planted and grow sustainably. The Cocoon has a water reservoir (storage capacity) of 25 L which fills once at a planting stage and then serves the water for the plant for six months. This technology is designed to prevent evaporation and weed growth around the base of the seedling (Land Life Company (LLC), 2015; Abdullah, 2017; Tapia et al., 2019). Water is transported from the Cocoon reservoir to the tree using wicks in which this protects seedlings from effects of harsh weather conditions and browsing by small animals, particularly during its first year (Land Life Company (LLC), 2015; Abdullah, 2017).

The increasing water shortage in the arid and semiarid degraded areas is the push-factor to investigate the sustainable use of Cocoon water-saving technology while transplanted tree seedlings. The existing reports from the Middle East and North Africa have indicated that use of Cocoon enables for better and successful survival and growth of planted tree seedlings on degraded soils in the arid and semiarid areas than the traditional tree planting system. Planting with Cocoon also helps restoring the top soil nutrients and soil structure as it is 100 % biodegradable (Abdullah, 2017; Land Life Company (LLC), 2015, 2016). Other important advantages of planting using Cocoon water-saving technology is that it is a low cost, needs no follow-up and no regular irrigation but enhances the survival rates of planted young seedlings between 75–95 % (Abdullah, 2017; Land Life Company (LLC), 2015; Faruqi et al., 2018). However, the specific effectiveness of the Cocoon water-saving technology detrimental effect on the survival and growth of transplanted mango seedlings should be tested before widely disseminated at large-scale in the arid and semiarid conditions of the northern Ethiopia.

In Tigray region (northern Ethiopia) such as the Rama area in each year different plantation activities have been conducted just after raising seedlings which demands intensive labor and other resources. However, after planted tree seedlings, the growers have been challenged by the poor survival rate (0–20%) due to moisture stress coupled with degraded soils. Such moisture stress could be associated with water scarcity to irrigate mango seedlings on steep land, erratic nature and short rainfall season and poor soil water holding capacity. Mihitsab-Azmati watershed in Rama area of northern Ethiopia is among the areas where problems of critical water scarcity and degraded soils have been observed and so challenged for proper establishment of tree seedlings. The objective of this study was to introduce the new knowledge and innovative idea of the Cocoon water-saving technology and evaluate its effectiveness on improving transplanted mango seedlings survival rate and growth performance at the early stage of mango trees as compared to the conventional practices.

2. Materials and methods

2.1. Description of the study area

This study was conducted in Mihitsab-Azmati watershed of the Rama area, northern Ethiopia (Fig. 1). The study was conducted from July 2018 to January 2020. The study watershed is located at 34 km from the north of the town of Adwa in Tigray region (Ethiopia) and 8 km from the border with Eritrea. The selected watershed falls within the Mereb sub-basin in Ethiopia. The total area coverage of the watershed is about 16,083 ha. In this study watershed, there is a reservoir finalized its construction in 2019 with a capacity to store water bout 28.5 million m^3. The area of the reservoir is about 108 ha. The irrigation production started since 2015 before the construction had finalized. The slope of the study watershed based on the FAO slope classification is flat, undulating, moderately sloping and steep to very steep lands but it is dominated by steep slope land. The altitude of the watershed ranges from 1400 to 3350 m above sea level, but the experimental site mean elevation is 1480 m above sea level (Bureau of Agriculture and Rural Development Office, BoARD, 2018).

The total household heads resided in the study watershed were 9554, with average family sizes of five (5). About 99 % of the farmers lived in the watershed are engaged under subsistence agriculture. The farmers have been used small degraded farm land with an average size of 0.5 ha per household head. The implication is that there is a need to use mountain agriculture with suitable technologies such as Cocoon in order to increase arable land size ad the corresponding productivity. The Mihitsab-Azmathi watershed has dominated by both lowland and midland agro-climatic conditions, but the experimental site is part of the lowland with arid climatic condition. It has mono-modal type of rain fall (July to September) with mean annual rainfall of 551 mm yr^{-1}. Likewise, the mean annual temperature is 19°c and the maximum and minimum temperature of 30°c and 11°c, respectively (BOARD, 2018).

The wide diversity in climate, topography and vegetation cover in the study watershed could be the cause for the marked variations in soil types, even within relatively small distance of the land plots. According to the farmers' classification, sandy soils are the dominant soil texture on undulating and steep slope lands. Such soil texture is highly susceptible to erosion and this gradually declined soil productivity. According to the FAO soil classification, four major soil types are available in the study watershed. These are: Cambisols, Solonchaks, Leptosols and Xerosols. The predominant type of soil mostly occurs in the undulating and rolling to hill topography part of the catchment is Leptosols (Food and Agriculture Organization of the United Nations, FAO, 1998).

The land use types in the study watershed includes bush land, bare land, cultivated land, forest land, home stead, grazing land, and reservoir area (dam). The cultivated land is dominated over the other land use types, but the experimental site used the marginal land above the reservoir after the construction of bench terraces. Field level observation indicated that the main crops grown are *bicolor sorghum* (Sorghum), *Eleusinecoracane* (finger milt), *Arachishypogaea* (ground nut), and *Zea mays* (maize). Vegetables and edible fruits are suitably grown in the study watershed. *Dodonaea viscosa* (Tahsos), *Euceleara cemosa* (Kuliow), *Ziziphus mauritiane* (Gava), *Acacia albida* (Momona), *Acacia bussei* (Gumero*Ficussy comorous* (Sagla)*, Euphorbia tirucalli* (Kinchib)*, Jatropha curcas* (Jatropha), are some of the tree species widely found in the study watershed. *Dodonaea viscosa* (Tahsos) is the most dominant tree in the lowland including the experimental site (BOARD, 2018; Personal Observation).

2.2. Experimental material, experimental design and procedures

This experiment was done using grafted mango seedlings which were planted as a test plant on the bench terraces built in the Mihitsab-Azmati watershed in Rama area, northern Ethiopia. Such bench terraces were built on the marginal area in the upper part of the reservoir by the local community who were involved under the project ``Climate Smart Integrated Watershed Management``, from Dec 2017 to April 2018. The area under bench terraces is about 1 ha. In this experiment, the Cocoon technology was used alone and with other practices while transplanted mango seedlings. The Cocoon has the capacity to hold 25 L of water and designed to fill once at a time to serve water for 6 months for the transplanted seedlings in the temperate environment condition. This is the duration used as a standard check the company designed the cocoon to give water constantly for the plant till the rainy month started. However, in the condition of the experimental site (tropical condition) it was observed that refilling of the Cocoon for the second time is crucial as the water in the Cocoon could not stay for six months. In this research, Cocoon was refilled with the same amount of water at three months after

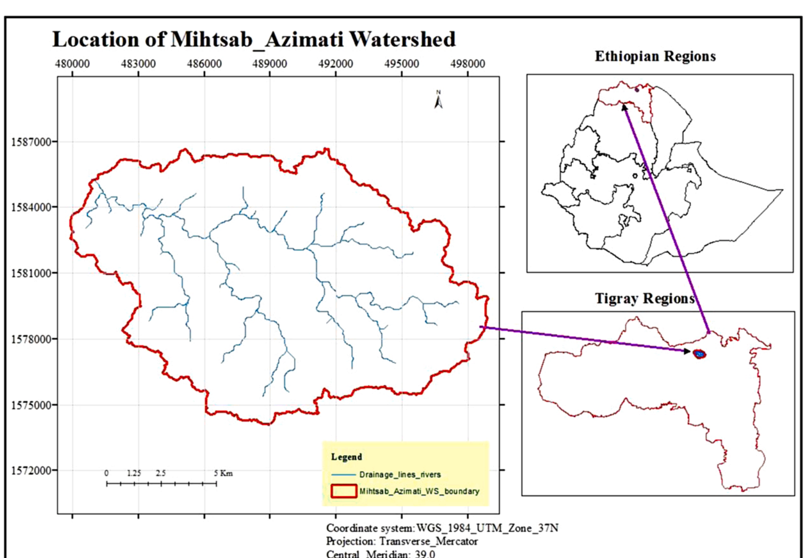

Fig. 1. Map of the study watershed in Tigray region, northern Ethiopia.

establishment. The Cocoon was put into the pit when the pit is free from stones and leveled. Before placing the Cocoon and the mango plant seedling, 10 L of water was added into the pit as described in (Land Life Company (LLC), 2019).

In this experiment, a total of five treatments related to the water-saving techniques with mango seedlings plantation were evaluated. These were: (i) Cocoon exterior part sprayed by tricel (T1), (ii) Cocoon exterior part painted by used engine oil (T2), (iii) Cocoon without tricel and oil i.e., 100 % biodegradable Cocoon (T3), (iv) Without Cocoon but mango seedlings manually irrigated (T4) and (v) Planted mango seedling without Cocoon water-saving technology mango seedling planted during the rainy season (T5). The tricel and oil were used to protect the Cocoon water-saving technology from termite attack during the dry period. Tricel is a broad spectrum organophosphorus insecticide. It controls a wide range of insects including termites. For this experiment, the recommended rate of tricel and used engine oil were used. Both trice and oil are categorized as repellents; implying termites avoid contact with a treated area which is part of their behavioral response (Su et al., 1982; Ibrahim et al., 2003). In this study, 1 g powder tricel mixed with 1 L of water was sprayed on the external part of the Cocoon. Three liters of used engine oil mixed with 0.5 L of diesel was painted on the exterior part of the Cocoon water-saving technology. The diesel makes the oil to be less viscous. The oil gives unpleasant test which repel or discourages termites from attacking the Cocoon. This is considered by the farmers as a traditional method that controls termite attacks.

The treatment manual irrigation (T4) has practiced for many years by smallholder farmers having small land holding size in areas where water is available for irrigation. Mango seedlings under manual irrigation were watered at 10 mm depth at three days interval until the rainfall started at the end of June 2019. Recently, manual irrigation practice using water cup and/ or furrow irrigation has been practiced widely by many farmers on the basis of availability of irrigation equipments though watering using a water cup is labor intensive. Irrigation using water cup may not be scalable as it is difficult to use with many seedlings planted at large scale. The treatment considered as 'with no Cocoon water-saving technology' of the mango seedlings planted during the rainy season (T5) were implemented during the rain-fed season on 01 July 2018. This was earlier by six months than the other

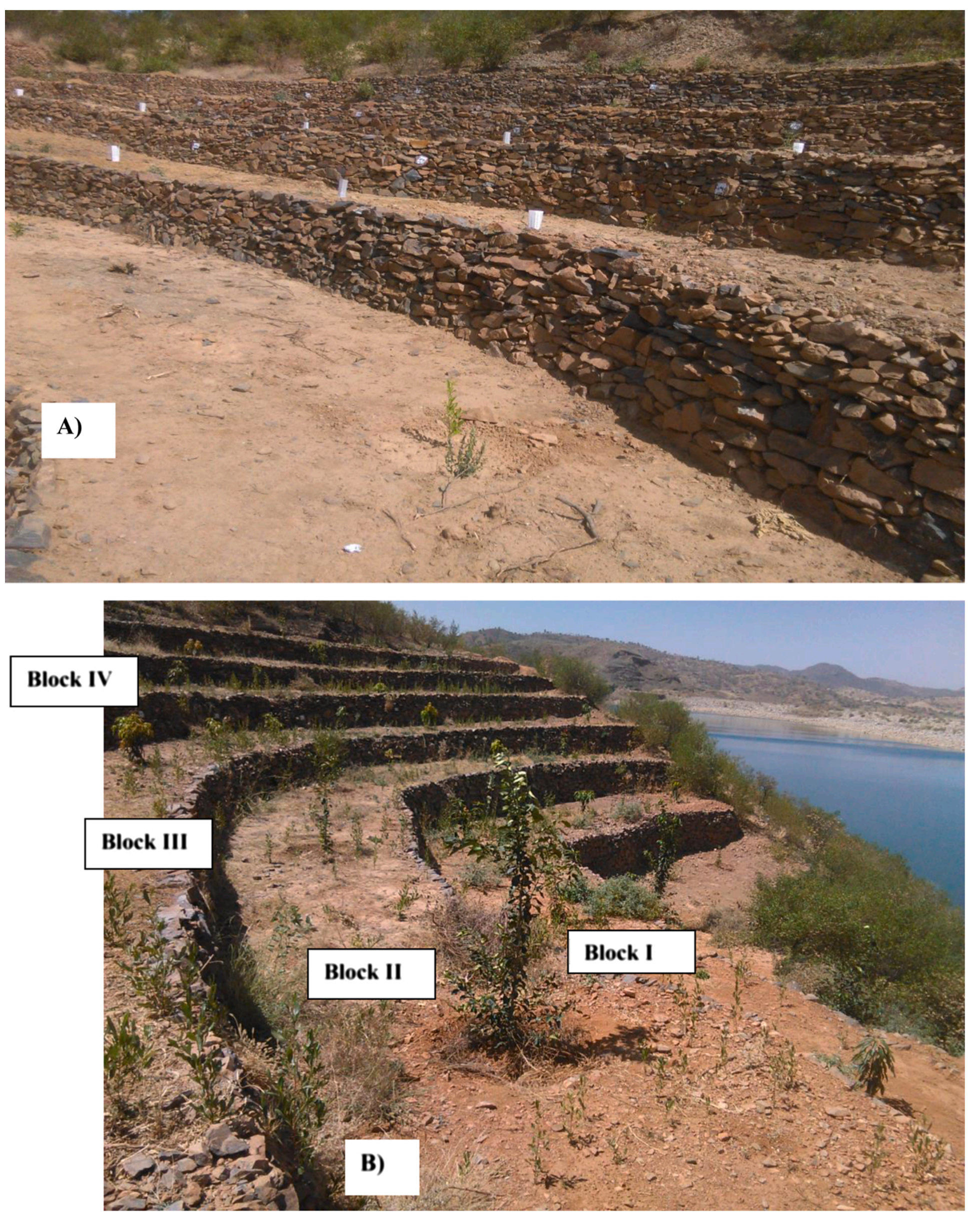

Fig. 2. Experimental design of mango plantation with and without Cocoon on the bench terraces of the upper catchment of the Mihitsab-Azmati reservoir in Rama area, northern Ethiopia: **A)** Mango plantation at planting time (Jan 2019); and **B)** One-year after planting (Jan 2020). (Source: Gebreyesus Brhane Tesfahunegn).

treatments which were planted on 01 Jan 2019. T5 was considered as a check or control because many farmers were practiced for many decades to establish fruit trees and other tree seedlings in areas where it is difficult to use irrigation infrastructure such as mountainous landscape of the study sites. Any of the other practices with all the treatments were implemented uniformly including the construction of the bench terraces. No chemical for pest and diseases control was used on the plant because there was no such problem on the mango plants.

The experimental design was laid down in Randomized Complete Block Design (RCBD) in four replications. This was fixed to have adequate number of mango plants for the treatments. Treatments were applied randomly in each blocks. The five treatments were implemented on one newly built bench terrace with a length of 60 m and this was considered as a block or replication (Fig. 2). The mango seedlings planted in each replicate of block was placed on a one of four 60 m length consecutive bench terraces. Each treatment replicate (plot) was represented by two trees. The spacing between plants in a block was 6 m and a distance of 4 m was maintained between seedlings planted in two consecutive bench terraces. The experimental site was closed from livestock interferences.

The illustration of how the Cocoon water-saving technology works with tree seedlings plantations is shown in Fig. 3. The pit size used to insert the Cocoon was 60 cm depth and 70 cm diameter. The Cocoon is closed with a biodegradable paper lid and completely covered and surrounded by locally sourced soils. Wicks inside the device transports water from the water filled Cocoon to the seedling's roots. Such drip system encourages roots to grow deep and wide, helping them tap into sub-surface soil moisture. The final step is to slide a cylindrical "shelter" over the Cocoon's opening, which protects the growing seedling from excessive sun exposure, winds, and small animals (Land Life Company (LLC), 2015; Jongejan, 2017; Union of Agricultural Committee (UAWC) and Fanack and Land Life Company (LLC), 2017).

Agronomical, the selected mango seedlings were watered before transported from the nursery to the planting site prepared on the bench terraces. Watering was done to protect the seedlings from drying up during transportation. During seedling transportation, caution was taken not to pile up as this can cause damage to the seedlings. The seedlings were transported upright in boxes as this reduces the chance of damaging the seedlings. Transported seedlings were planted with respect to all the treatments just immediately at the same date of the transportation.

2.3. Data collection and procedures

Data on survival rate and other growth performance indicators of the mango seedlings planted with respect to the treatments effects were collected two times, i.e., at six months, and one-year after transplanted. The first period of data collection was just at six months (30 June 2019) after transplanted the mango seedlings with respect to all the other treatments except T5. The first (at six months) and second periods (at one-year) of data collection with regard to T5 were on 31 Dec 2018 and 30 June 2019, respectively. All data from T5 were collected just after one rainy season (July and August 2018). The second period of data collection for the rest of the treatments was just at one-year (01 January 2020) from the date of the mango seedlings transplanted. In this experiment, survival rate, plant height, numbers of leaves per plant, shoot length, stem diameter and crown width were the parameters collected during the two data collection periods described on the above. Details of each parameters collected are described as follows.

Survival rate of mango seedlings planted with respect to the five treatments were recorded just at six months and one-year from the date of the seedlings transplanted. Finally, the survival rate in percentage was calculated with respect to each of the treatments (Tapia et al., 2019) as:

$$Survival\ rate\ (\%) = \frac{Number\ of\ survived\ seedlings}{Number\ of\ planted\ seedlings} \times 100\% \quad (1)$$

Plant height (cm) of the mango seedlings planted was measured from the attachment on the ground level up-to the tip of the growing point (Fig. 4A). This was recorded from all the plants treated using the five treatments in each blocks. All the mango plants in all the blocks were recorded using tape meter at six months and at one-year after the date of transplanted.

The total numbers of leaves per plant were counted from all the mango plants treated by the five treatments in each blocks twice, i.e., at six months and one-year after transplanting. Similarly, the diameter of the main stem (cm) was measured at 5 cm above the ground level (the thickest part) with the help of graduated caliper just from all of the treatments during the two data collection periods. Terminal shoot length (cm) was also recorded using tape meter at the tip of the plant leaves from all the mango seedlings transplanted (Fig. 4B) in each blocks just at six and one-year after the date of transplanted.. In addition, crown width (cm) was measured from all the seedlings of mango planted in each blocks with respect to the five treatments during the two data collection periods. Crown width was estimated by pacing the diameter of the canopy from two directions perpendicular to each other (Brack, 1997).

2.4. Data analysis

Data were subjected to analysis of variance using Statistix 10 software (Analytical Software, Tallahassee, FL). Means of treatment effects were considered significant at the probability level (P) $\leq$ 0.05. Mean of the treatment effects was separated using the Least Significant Difference (LSD) at P $\leq$ 0.05. Survival rate and number of leaves per plant were log-transformed to meet the assumptions of normality.

Paired-Samples *t*-test at P $\leq$ 0.05 was used for paired mean difference comparison between values of the same growth parameter response to

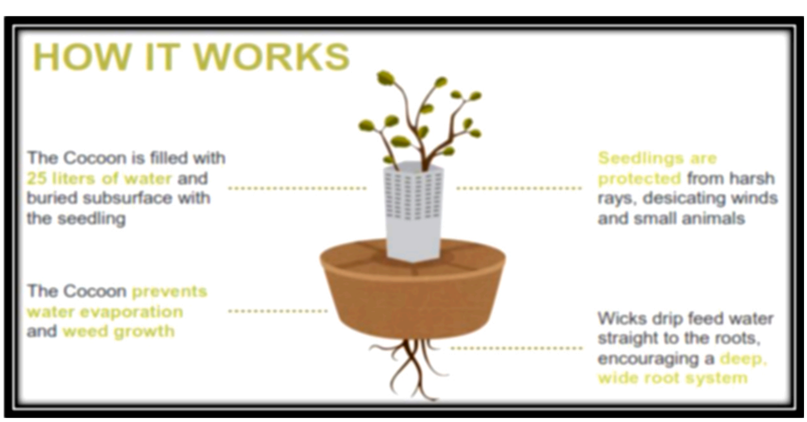

Fig. 3. Illustration of how the Cocoon water-saving technology works with seedling plantation. (Source: UAWC, Fanack and Land Life Company, 2017).

Fig. 4. Mango plant with Cocoon treated using tricel and oil just at one-year after transplanting in the Rama area, northern Ethiopia: A) Plant height measurement; and B) Terminal shoot length measurement. (Source: Gebreyesus Brhane Tesfahunegn in Jan 2020).

the different treatments determined across the two data collection periods (at six months and one-year after transplanting). This *t*-test procedure was used to test the null hypothesis stated as "There was no significant difference in mango plant growth increment measured at six months and one-year just after transplanted due to the effects of the treatments."

3. Results and discussion

3.1. Effects on survival rate and growth performance at six months after transplanted

In this study, the survival rate and growth performance of mango plant seedlings transplanted with respect to the effects of the different treatments is shown in Table 1. The survival rates of the mongo plants treated with the five treatments at six months after transplanting were significantly influenced by the treatments. The significantly lowest survival rate (20 %) six months after seedlings transplanted was in the control treatment (T5). All the other treatments had a 100 % survival rate at six months after transplanting. This indicates that the use of Cocoon water-saving technology with or without tricel or oil could improve survival rate better than the standard local farm practices in the study area conditions. The 100 % survival rate six months after transplanting in this study is higher than that reported for Cocoon technologies in other studies elsewhere between 75–95 % (e.g., Land Life Company (LLC), 2015; Abdullah, 2017; Faruqi et al., 2018). The present finding of the water-saving techniques could be a solution for the concern of the greatest mortality risk (poor survival rate) of seedlings planted upto the first year of the plant after transplantation which reported by Menendez and Jaramillo (2015) and Tapia et al. (2019). This is because there was 100 % seedling survival rate upto one year after transplanting due to the Cocoon water-saving techniques tested in this study.

Table 1
Effects of water-saving techniques on survival and growth performance of mango seedlings plantation at six months after transplanting in Rama area, northern Ethiopia.

Treatments treated for mango seedlings plantation	Survival rate (%)	Plant height (cm)	NL per plant	Shoot length (cm)	Stem dia. (cm)	Crown width (cm)
Cocoon exterior part sprayed with tricel (T1)	100a	40.2a	25.0a	12.6a	1.94a	25.6a
Cocoon painted by used engine oil (T2)	100a	39.8a	23.0a	12.3a	1.89a	23.9ab
Cocoon without tricel and oil or 100 % biodegradable Cocoon (T3)	100a	38.2a	21.0a	6.5b	1.40b	21.9b
Without Cocoon but manually irrigated (T4)	100a	37.2a	16.0b	6.3b	1.18bc	20.3bc
Planted mango seedlings without Cocoon during the rainy season (T5)-control	20b	25.0b	10.0c	5.0c	1.10c	16.0c
LSD ($P \leq 5\%$)	0.015	0.038	0.031	0.024	0.026	0.035
CV (%)	7.57	10.50	9.98	8.62	7.98	8.62

NL, number of leaves; dia., diameter; LSD, Least significant difference at probability level (P) ≤ 5%;CV, coefficient of variance.

There were significant differences in mango plant heights between the control (T5) and the rest of the treatments measured at six months after transplanting (Table 1). However, there were non-significant differences in plant heights measured at six months after transplanting among T1, T2, T3 and T4. During the six months after trnsplanted, the highest plant height was measured from mango plants treated by the Cocoon exterior part sprayed with tricel (T1) (40.2 cm) followed by Cocoon exterior part painted by used engine oil (T2) (39.8 cm). The shortest mango plant height was measured from mango seedlings treated by the control (T5) (25.0 cm) followed by T4 (37.2 cm). Regardless of the non-significant difference, T1 resulted in a plant height higher by 3 cm (8.1 %) as compared to that of T4 measured at six months after transplanting. Such difference in mango plant heights after transplanted in this short period of time is quite important to imply the treatments contribution in the study area conditions. It is also important to note that mango seedlings with equal height were selected during the transplanted time and the same planting depth was used to avoid errors related to plant height measurement among the treatments.

There were significant differences in the number of leaves per plant of the mango seedlings counted at six months after transplanting due to the treatments treated using the Cocoon water-saving technologies (T1 to T3), manually irrigated (T4) and planted with rain-fed (T5). However, there were non-significant differences in the number of leaves per plant of the transplanted mango plants counted at six months among the cocoon technologies (Table 1). The number of leaves per mango plant counted at six months after transplantation with respect to the treatment effects of the Cocoon water-saving technology without tricel and oil (T3) were significantly lower than those plants treated by the Cocoon sprayed with tricel (T1) and Cocoon exterior part painted by used engine oil (T2). The reason could be attributed to the nature of tricel and oil painted Cocoon which protects the Cocoon from being biodegraded by termites and other biological attacks while serving water to the plant.

Mango tree seedling leaves per plant were recorded during the planting time and excluded from the analysis in order to see only the treatment effect after transplanting on the number of leaves in a plant. Generally, the highest number of leaves per mango plant was recorded from plants treated with T1 (25.0) whereas the lowest number of leaves per plant was found from mango plants treated with T5 followed by T4 (Table 1). Such result on the numbers of leaves indicate that mango plants with Cocoon could access water stored in the Cocoon constantly during the entire dry period whereas the manually irrigated plants may expose to water stress within the irrigation interval due to a higher evaporation, transpiration, and/or deep-percolation flow losses beyond the root zone (Tesfahunegn, 2019; Gebru and Tesfahunegn, 2020). Such losses may affect the mango plant growth including the number of leaves even within the six months after transplanting. With regard to T5, it has only two months to access moisture from the seasonal natural rainfall and after this the long dry-months affects negatively the growth parameters of the mango plant (Abdullah, 2017; Faruqi et al., 2018; Comparini et al., 2020).

The significantly highest shoot length at six months was in T1 (12.6 cm) followed by T2 (12.3 cm) was measured just after transplanted. The lowest in shoot length of the transplanted mango seedling measured at six months was due to T5 (5.0 cm) followed by T4 (6.3 cm). Similarly, the significantly highest stem diameter (1.94 cm) of the mango plants measured at six months after transplanting was due to T1. The significantly lowest stem diameter of 1.10 cm due to T5 followed by T4 (1.18 cm) of the mango plants were measured at six months after transplanting. There were non-significant differences in the stem diameter of the mango plants measured at six months after transplanting with respect to the effects of T1 and T2 (Table 1), in which this could be attributed to the similarity of both Cocoon treatments with anti-termite chemicals.

Crown width of the mango plants measured at six months after transplanting showed significantly differences among most of the treatments. The highest crown width was found due to T1 (25.6 cm) whereas the lowest was due to T5 (16.0 cm). However, there were non-significant differences in crown widths measured at six months after transplanting between the effects of T1 and T2; and T3 and T4 (Table 1), indicating that such treatments have similarity in the effects on crown width.

3.2. Effects on survival rate and growth performance at one-year after transplanted

The mean value of survival rate, plant height, number of leaves per plant, shoot length, stem diameter and crown width measured at one-year after mango plant seedlings transplanting is shown in Table 2. The survival rates of the mango seedlings at one-year after transplanting influenced significantly by the treatments effects. The lowest survival rate was in T5 (20 %) whereas a 100 % survival rate from the other treatments were reported. This indicates that there was positive treatments effect on the survival rate of mango plants transplanted due to the water-saving techniques described as T1, T2, T3 and T4. On the other hand, the present result indicates that in the absence of water-saving technology in the long dry periods, survival rate of seedlings transplanted treated using T5 were reported as very poor. This implies that there is a high benefit to adopt the Cocoon water-saving technologies that improve survival rate using small amount of water application in the dry season. In support of this, field observation on the same landscape indicated that the mean survival rate of graveala tree species seedlings planted during the same rainy season without Cocoon and with no supplementary irrigation application during the dry months was reported as 10 %. This indicates that soil moisture is a critical issue for improving the survival of seedlings planted and growth performance at the early growth stage in the study area conditions.

Table 2
Effects of water-saving techniques on survival and growth performance of mango seedlings measured at one-year after transplanting in Rama area, northern Ethiopia.

Treatments treated on mango seedlings	Survival rate (%)	Plant height (cm)	NL per plant	Shoot length (cm)	Stem dia. (cm)	Crown width (cm)
Cocoon exterior part sprayed with tricel (T1)	100a	65.0c	54.0c	16.0c	3.75c	36.0c
Cocoon painted by used engine oil (T2)	100a	78.3b	61.0b	18.7b	4.17b	40.3b
Cocoon without tricel and oil or 100 % biodegradable Cocoon (T3)	100a	83.3a	67.0a	26.3a	4.83a	45.3a
Without Cocoon but manually irrigated (T4)	100a	47.0d	28.0d	9.67d	3.57c	26.7d
Planted mango seedlings without Cocoon during the rainy season (T5)-control	25b	32.0e	17.0e	6.5e	1.25d	16.0e
LSD ($P \leq 5\%$)	0.015	0.017	0.015	0.024	0.025	0.014
CV (%)	7.57	11.8	13.5	9.07	8.21	12.6

NL, number of leaves; dia., diameter; LSD, Least significant difference at probability level (P) ≤ 5%; CV, coefficient of variance.

The plant heights of mango seedlings measured at one-year after transplanting were significantly influenced by the treatment effects (Table 2). The highest plant height was measured from T3 (83.3 cm) followed by T2 (78.3 cm). On the other hand, the shortest plant height of mango plant measured at one-year after transplanting was due to T5 (32.0 cm) followed by T4 (47.0 cm). The changes in plant height increments between the two measurement periods for T3, T2, T1, T4 and T5 in descending order were 45.1, 38.5, 24.8, 9.8 and 7.0 cm, respectively (Tables 1 and 2). This indicates that the highest mango plant height increment was due to T3 followed by T2. This could be associated with the Cocoon water-saving technology that supplies constantly water for six months after the seedlings transplanted and also its contribution to improve topsoil as it is biodegraded. Even though the study area is well known for the problem of termite; fortunately, T3 which was without any termite protection performed its intended purpose of water supply and soil nutrients (biodegraded) to the transplanted mango seedlings. The Cocoon water-saving technology used with tricel and oil can supply constantly water for six months after the seedlings transplanted. However, such sprayed and painted substances could reduce Cocoon from being biodegraded on time and thereby it has insufficient contribution to add plant nutrients and improve soil structure. This may be lower the plant height increment due to T1 and T2 as compared to T3. Practically, it was observed at field level that the Cocoon water-saving technologies used with tricel and oil were less biodegraded even after one-year (Fig. 4).

The numbers of leaves per plant measured at one-year after transplanting were significantly influenced by the treatments (Table 2). The highest mean numbers of leaves per mango plant were observed in T3 (67.0) followed by T2 (61.0). The lowest mean numbers of leaves per mango plant (17.0) at one-year after transplanting was due to T5. Within six months (July 2019 to Dec 2019), there was nearly more than three folds increment in the mean number of leaves per mango plant with response to T3 and slightly less than three folds due to T2 (Tables 1and

2). Similarly, there were significant differences in shoot length measured at one-year after transplanting due to the treatments effects. The highest shoot length (26.3 cm) was measured from T3 whereas the lowest shoot length (6.5 cm) was from the mango plants treated by T5. The shoot length measured from mango plants treated with T2 was slightly higher than that of T1 which could be associated with the differences in the level of their degradation and constant water supplying to the plant root.

In addition, there were significant differences in the mean stem diameter of mango plants determined at one-year after transplanting due to the effects of the treatments. The highest stem diameter (4.83 cm) of mango plant measured at one-year after transplanting was due to T3. This was followed by the effect of T2 on stem diameter (4.17 cm). The lowest stem diameter of mango plants (1.25 cm) was measured due to T5 in the study area. The increment in stem diameter after measurement taken at six months up-to 12 months after transplanting (July 2019 to Dec 2019) due to the effect of T3 was 3.44 cm which is the fastest stem diameter growth as compared to the other treatments. Significant differences in crown widths of the mango plant measured at one-year after transplanting were reported with respect to the treatment effects. In a similar manner, the highest crown width of the mango plants at one-year after transplanting was measured from T3 (45.3 cm) followed by T2 (40.3 cm). On the contrary, the lowest mean crown width value of the mango plant was measured from plants treated using T5 (16.0 cm) at one-year after transplanting. The result of T3 indicated that the best growth performance of the mango seedlings at one-year after transplanting provided that if the site is free of termite; otherwise termites can be destroyed the Cocoon within less than 2 months.

3.3. Paired mean difference of growth parameters between two measurement periods

In this study, the paired mean differences between the same growth parameter of mango plant measured at one-year and six months after transplanted showed significant differences (Table 3). For example, the overall treatments effect on mean difference between plant height measured at one-year and six months after transplanted is 29.6 cm. This value is within the lower and upper confidence interval, with acceptable standard error of mean (4.8 cm) indicating that such result is representative for the target population at confidence level of 95.2 %. The same interpretation can be used for the remaining paired mean differences values of the parameters indicated in Table 3. The implication of the significant difference of the paired mean differences of the growth parameter of mango transplanted seedlings between the two measurement periods is that the Cocoon technology is not only important during the first six months of the dry season just after transplanted but also it has even better contribution to increase the growth of mango plants up-to 12 months. This could be related to the fact that the plant may use the biodegraded Cocoon as source of nutrients and improving soil water holding capacity during the rainy season. A well established seedling during the first six months after transplanted can develop a root system that has good capacity to use nutrients and soil water from the soil profile. However, further detail research should be conducted to know scientifically the reason for such significantly increment in the growth parameters after the six months of the mango seedling transplanted from the point of view of soil nutrient and water dynamics.

3.4. Synthesis of treatments effects on mango growth performance after transplanted

This study demonstrated that the Cocoon technology was effective in increasing the survival rate and growth performance of the transplanted mango seedlings. Six months after transplanting, the Cocoon technology with tricel (T1) was superior and positively affecting the growth performance as compared to the other treatments. However, the increment in the growth of the mango seedlings one-year after the transplanting was significantly higher in the Cocoon without tricel and oil (T3) than the other treatments. Also, the three treatments of Cocoon water-saving technologies (T1, T2 and T3) were all found to ensure the best survival rate. The survival rate due to T4 was also as effective as the Cocoon treatments, but used much water and labor. However, T4 showed significantly lower values of the other growth performance indicators than the treatments with Cocoon water-saving technology. In support of this result, the existing reports have shown that the use of Cocoon supports the current practices in nature restoration and sustainable agriculture as it has completely eliminated irrigation and enhanced the survival rates and vigor of young seedlings (e.g., Land Life Company (LLC), 2015, 2016; Abdullah, 2017; Wei et al., 2017). According to the report by Union of Agricultural Committee (UAWC) and Fanack and Land Life Company (LLC), 2017, comparatively, the Cocoon uses on average a total of 25 L of water to achieve seedlings survival rates of 75–95 % on olive and almond planted trees in the Gaza Strip. This survival rate is lower than the present result on survival reported at six and 12 months after mango seedlings transplanting which was 100 % with the Cocoon water-saving technologies. This indicates that Cocoon water-saving technologies could support the seedlings to survive and grow in the dry months of a year, Cocoon stimulates plant roots to grow to a sufficient depth and use available water and nutrients from the soil profile on their own (Lampayan et.al., 2004; Jaramillo et al., 2015a, b; Land Life Company (LLC), 2019).

The Cocoon water-saving technology was found effective and so preferred over the other treatments such as T4 due to the following observed points. The first point is the use of Cocoon reduces labor costs

Table 3
t-test of paired mean differences of the treatments effects on growth performance of mango seedling measured at six months and one-year after transplanting in Rama area, northern Ethiopia.

Paired	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Dev.	Std. Error Mean	95 % Confidence Interval of the Difference				
				Lower	Upper			
Ph1 - Ph6	29.6	9.6	4.80	4.65	54.4	3.78	4	0.033*
NL1 - NL6	31.8	8.5	4.25	8.69	54.8	4.38	4	0.022*
SL1 - SL6	8.19	7.9	3.95	4.34	20.7	3.08	4	0.039*
SD1 - SD6	2.61	0.68	0.34	1.52	3.69	7.61	4	0.005**
CW1 - CW6	19.1	9.8	4.90	7.34	45.6	3.30	4	0.035*

* and **, significant at 0.05 and 0.01 probability levels (P), respectively.
Ph1-Ph6 is plant height measured at one-year after transplanted minus plant height measured at six months after transplanted.
NL1-NL6 is number of leaves counted at one-year after transplanted minus number of leaves counted at six months after transplanted.
SL1-SL2 is shoot length measured at one-year after transplanted minus shoot length measured at six months after transplanted.
SD1-SD6 is stem diameter measured at one-year after transplanted minus stem diameter measured at six months after transplanted.
CW1-CW6 is crown width measured at one-year after transplanted minus crown width measured at six months after transplanted.
[t] is *t*-test value; and df is degree of freedom.

as water is added one time during the installation stage as compared to the manually irrigated at three days interval. The Cocoon eliminates the need for regular irrigation systems, and so reducing significantly the labor costs related to water and its application on the seedlings transplanted. On the contrary, the experiences of farmers who involved on irrigation from small ponds and shallow wells in the Tigray region and other regions of Ethiopia showed that irrigation practice is expensive as demands intensive water and energy. Meaning, it consumes high energy to extract and convey water as well as costs related to installation, maintenance and removal of irrigation infrastructures. Secondly, the amount of water being added to the Cocoon technology is about 25 L in temperate zone and 50 L in tropical conditions (refilled) which is used for about six months in which this amount is by far lower than the manual irrigation. Thirdly, water losses as a result of evaporation, lateral and vertical flows beyond the root zone, and water being used by weeds growing around the mango plants were very low with the Cocoon as the structure of this technology prevents such losses. Fourthly, once planting with Cocoon water-saving technology is finished, it will not require maintenance or removal as Cocoon will degrade within two years after installation (Land Life Company (LLC), 2015, 2016; Land Life Company (LLC), 2019).Under such conditions the Cocoon water-saving technology enhances the survival rate and growth performance of the planted seedlings during the dry months; otherwise the poor survival rate in the conventional approach means that efforts have to be undertaken for re-planting that adds again a cost to a plantation program. Finally, the collective effects of the above core points indicate that the Cocoon water-saving technology is sustainable and highly scalable for its application while planting with seedlings of suitable tree species such as mango seedling transplanted at large-scale in the arid and semiarid degraded areas (Land Life Company (LLC), 2015, 2016; Union of Agricultural Committee (UAWC) and Fanack and Land Life Company (LLC), 2017). Similarly, the Cocoon water-saving technology is effective in landscaping such as road sides and public parks as this reduces irrigation water consumption and labor costs for irrigation and irrigation system installations and maintenances (Wei et al., 2017).

On the basis of this study result, in termite suspected sites it is suggested to use the Cocoon water-saving technology with tricel or used engine oil so that to protect from termite attacks over the lifetime of the Cocoon. However, in such conditions, it should be realized that the Cocoon biodegradable status is going to be reduced. So, the expected contribution towards soil nutrient improvement may not be addressed in the presence of anti-termite painting or spray on the exterior part of the Cocoon. Hence, plantations that are being planned to execute on degraded soils should be considered for the application of external organic fertilizer sources if we use Cocoon with tricel or used engine oil as this reduces the Cocoon biodegradability (Cabin, 2007; Jaramillo, 2015).

Generally, in agreement to the present findings of the Cocoon water-saving technology that influenced significantly on survival and growth performance of mango seedlings transplanted, Tapia et al. (2019) have reported that the survival and growth of Opuntia species plantings had improved by the water-saving technology such as Groasis Waterboxx. However, the same authors have stated that the advantage of such technology is highly dependent upon the planting environmental conditions (.e.g., elevation, vegetation zone, precipitation) and species types. The implication is that it is better to emphasize on the species types and site-specific conditions while selecting and applying the above water-saving technology for successful plant restoration in the dry areas with degraded soils (Kulkarni, 2011; Jaramillo, 2015; Tapia et al., 2019). In support of this, the Cocoon water-saving technology could not contribute for the improvement of *Opuntia cacti* growth and rather reduced the probability of the survival rate of the seedlings of *Opuntia* plantings by 89 % (Tapia et al., 2019)). One possible explanation is that *Opuntia cacti* species have a short root depth which has not matched with the Cocoon depth as compared to other species with deep roots (Tapia et al., 2019; Snyman, 2005). Under such condition, this may reduce *Opuntia cacti* roots access to the water stored in the Cocoon (Land Life Company (LLC), 2015; Tapia et al., 2019). On the other hand, *Acacia macracantha* with deeper roots had showed better success when planted with the Cocoon water-saving technology in the Galápagos area (Kulkarni, 2011; Tapia et al., 2019). Such findings, however, do not undermine the contribution of Cocoon for plant restoration purposes in water stressed degraded soils; rather underlined the significant observation that water-saving technologies should be considered on a case-by-case and tested with each species under various environmental conditions before planning expansive planting activities at large-scale (Tapia et al., 2019).

4. Conclusion

This study revealed a 100 % survival of the mango seedlings planted with Cocoon water-saving technologies (T1, T2 and T3), whereas the seedlings planted without Cocoon during the rainfall season (T5) showed a survival rate of 20 % at six and 12 months after transplanting. The survival rate of mango seedling with manual irrigation (T4) was also found to be 100 %. To select the best practice for improving seedling survival rate among the treatments, understanding comparative advantage of Cocoon and manual irrigation with respect to amount of water and labor is crucial. For example, the Cocoon technology is water-saving as uses small amount of water (25 L) just applied at one time, as compared to the manually irrigated at three days` interval which requires much water and labor to achieve the same plant survival rate.

The growth performance indicators of mango (plant height, number of leaves per plant, shoot length, stem diameter and crown width) measured at six and 12 months after transplanted were significantly influenced by the Cocoon water-saving technology. The highest growth parameters were measured at six months after transplanting due to Cocoon exterior part sprayed by tricel (T1) whereas the lowest values were from T5. However, the highest growth parameters measured at 12 months after transplanting were due to the effect of Cocoon without tricel and oil i.e., 100 % biodegradable Cocoon (T3). This could be attributed to the contribution of biodegraded Cocoon towards soil nutrients and structure improvement in which the mango plants are being expected to use for growth. The Cocoon sprayed by tricel or painted using used engine oil increased the lifetime of the Cocoon biodegradability even more than a year. In such condition, application of external sources of organic fertilizer is highly suggested as plantation on degraded soils suffers from lack of adequate soil nutrients for plant growth. In areas whereby termite is not a problem, the use of the Cocoon without tricel and oil is highly recommended to improve the growth performance of mango seedlings plantation through improving water use efficiency and soil system while reducing losses of water and labor costs. The use of the water-saving Cocoon technology reduces the amount of water applied and used by the mango trees after transplanted as compared to the traditional irrigation method, in which this could save an additional advantage. On the basis of this study, the 100 % biodegradable Cocoon seems sustainable and highly scalable for its application with seedlings of mango tree species in termite free arid and semiarid degraded areas at large-scale. This technology is thus expected to be a solution for the problem related to poor survival rate and other growth parameters of planted tree species using the conventional approach in which this has been remained a critical problem for a longtime in the study area conditions.

Finally, this study underlines that water-saving technology such as Cocoon is a promising system as it has a profound influence on mango tree seedlings survival rate and plant growth performance in the degraded soils of the arid environment. However, this technology should not be assumed to function uniformly well in all environmental conditions and with all tree species before demonstrating on a pilot study. Pilot testing on extensive environmental conditions with degraded soils and different restoring species is essential before large-scale planting efforts with Cocoon water-saving technology are planned and initiated.

A cost-benefit analysis of the Cocoon water-saving technologies over the conventional practices on mango tree seedlings plantation should also be investigated.

Conflict of Interest Declaration

The authors declare that they have no conflict of interest.

Ethical statement

All ethical practices have been followed in relation to the development, writing, and publication of the article.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.agwat.2020.106476.

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