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PERFORMANCE EVALUATION OF AN OFF-ROAD LIGHT AERIAL PLATFORM FOR DATE PALM (*Phoenix dactylifera* L.) CULTIVATION

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Performance Evaluation of an Off-Road Light Aerial Platform for Date Palm (*Phoenix dactylifera* L.) Cultivation

Master of Science Thesis

By

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“Whatever it is that you want to accomplish, don't bother to do it better than others; just stay focused on the best possible version that you can provide.”

Enrico Bonaiuti

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At the end of a long and complex journey as the Master of Science degree one is, it is not easy to acknowledge properly all the people I would like to.

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LIST OF ABBREVIATIONS AND ACRONYMS

%	Percent
Ah	Ampere hour
°C	Degree Celsius
DDP	Days Post-Pollination
H	Hour
Ha	Hectare
H.K.	Hashemite Kingdom
Kg	Kilogram
kPa	Kilopascal
kW	Kilowatt
L	Liter
M	Meter
min (mm)	Minute
s (ss)	Second
T	Ton
V	Volts

ABSTRACT

Date palm (*Phoenix dactylifera* L.) cultivation is characterized by several operations performed at the frond level. Fronds can be many meters above the ground, especially in older groves or plantations. Mechanization in date palm farms is still lacking or inadequate, especially in medium and small farms of non-industrialized countries, and operations at the frond level are still done manually by climbing up the tree. Working at height without specific equipment is difficult, tiring and risky and many accidents occur to workers when climbing on taller palms with the traditional belt-based climbing system. In large specialized plantations of valuable date varieties, aerial platforms are used, generally derived from the construction industry, with or without adaptations to the specific task. Nevertheless, the high purchase price and maintenance costs don't allow for their use in smaller farms.

However even medium sized groves, where high value varieties are cultivated such as the world renowned Medjool in the Jordan Valley (H.K. of Jordan), could benefit of specialized mechanized equipment if of adequate size and cost, but suitable solutions have been missing until now.

With the aim of proposing a versatile machine for aerial operations in date palm medium-sized farms, in 2016 the Italian manufacturers CO.ME.T. and ERREPPI marketed a compact aerial platform mounted on an off-road light carrier, specifically designed for use in palm plantations.

The objective of this study is the evaluation of this self-moving aerial platform, named Xiraffe, in terms of timing, effectiveness and general attitude to work along the date palm cultivation process. This analysis is based on observations done and data collected in 2017, during harvesting field trials on Medjool date palms in the Jordan Valley. These trials, carried out on palms of different height and characteristics, aimed at comparing mechanized and traditional manual harvesting, which is still the most common method in the study area. The results showed that this small sized and agile machine proves to be effective while capable of improving work safety and timing when used to harvest palms between 6.0 and 9.4 meters high. However, the manual harvest is still more effective for medium and small farms in the test environment, but some technical improvement to the platform, such as modifying the bucket shape or providing it with specific tools for other operations (e.g. pruning, bagging or pollination), can reduce the gap, opening a completely new scenario in date palm cultivation.

Keywords: Medjool dates, Jordan, agricultural mechanization, harvesting, lifting of operators.

INTRODUCTION

Date palm (*Phoenix dactylifera* L.) is considered one of the most valuable and important fruit crop in its main distribution area of the Middle East and North Africa. It is among the very few plants that can thrive in arid environments and can provide significant resources for local populations (Chao and Krueger, 2007). More recently, because of the characteristics of the fruits that are appreciated in all the world, it was introduced in new areas such as America, Australia, Namibia, etc. (Garbati Pegna, 2008). In the last few decades, date production has grown extraordinarily and is expected to continue to raise (Chao and Krueger, 2007). Worldwide it has increased from 6,440,583 t in 2000 to 8,460,443 t in 2016, while the harvested area has expanded from 1,051,482 ha in 2000 to 1,353,159 ha in 2016 (fig. 1) (FAOSTAT, 2018).

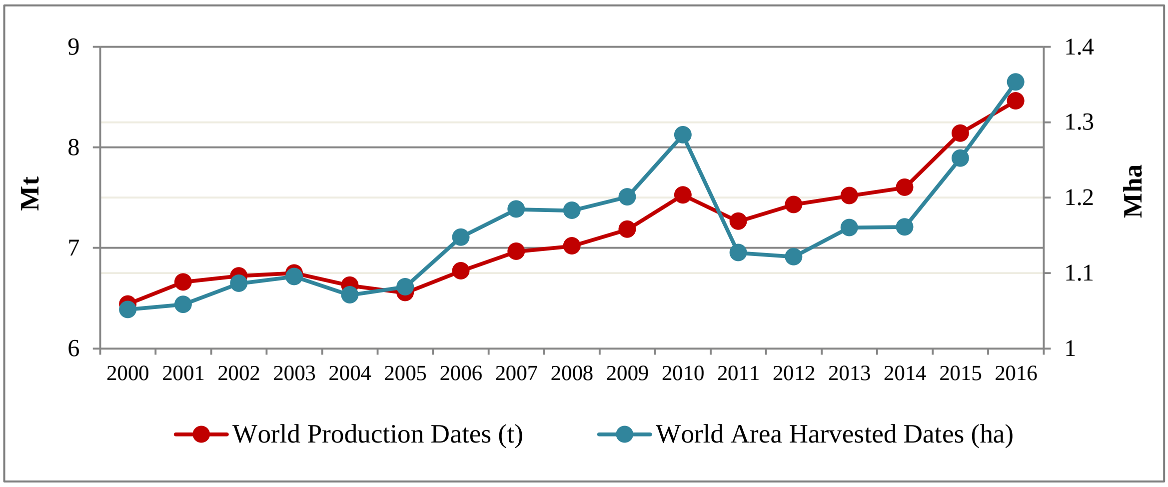

Figure 1. Date palm cultivation in the world (Source FAOSTAT 2018).

This positive trend is also forcing date cultivation to develop new solutions to face the modern production challenges: timeliness of agricultural practices, increasing labor costs, scarcity of skilled labor, fatigue and risks inherent in this work are part of the main issues to address. In fact, date palm cultivation is characterized by several operations performed at the frond level which is often at more than 6 m above the ground and can reach up to 20 m in old plantations. In most plantations access to the frond level is still performed in traditional ways, where workers have to climb up the trunk with the help of belts or straps or long ladders or of other people piled up on each other’s shoulders (Opara, 2003 in Garbati Pegna, 2008, Nourani, 2016). This makes these operations, among which harvest is obviously the most important, very difficult and risky, especially when palm height is over

6-8 m, causing many victims yearly or the abandoning of the higher palms (Garbati Pegna, 2008).

A major change that has occurred in date cultivation in the United States has been the mechanization of some cultivation practices and in particular the timing and method of harvesting (Barreveld, 1993 in Akyurt, 2002). During 1940's and 1950's, under the impact of increasing labor costs and ever-increasing height of the palms, some growers in the U.S. built large tractor-pulled harvesting towers, to avoid the need for ladders (Akyurt, 2002); starting from 1960, the use of truck-mounted hydraulic crane-like man-positioning machines was experimented, in order to move workers from palm to palm (Akyurt, 2002). Even if none of these attempts provided a significant increase in workers' productivity, the scarcity of labor was such that by 1966, 80% of the date crop in the US was being harvested with the use of these mechanical devices (Brown, 1983 in Akyurt, 2002). Nowadays other machines, which can harvest dates by shaking the plant or that by a slider mechanism and a grip force on the stem can climb up the operator to the frond, have been developed but these devices are not suitable for most date varieties and they still need many improvements (Shamsi, 1998). One of the most important steps forward in mechanizing operators' access to the fronds, flowers and fruits of date palms has been a large "U" shaped aerial platform, hold by a hydraulically moved telescopic boom or forklift mounted on an off-road carrier, that can provide support and space to several workers allowing them to work on a palm at the same time. This system, which offers good levels of efficiency and safety for workers and allows a faster repayment of the investment, is widely used in large specialized plantations where valuable varieties are cultivated. However, the high purchase and maintenance costs of this equipment make it not affordable for the medium and small farms (Garbati, 2008 and Shamsi, 1998). Further limits may be identified in difficulties of maneuvering in tight spaces caused by irrigation systems, an irregular layout of palms, insufficient tree spacing and intercropping (Shamsi, 1998). In some of these cases, or where different equipment is used, operators have to jump out from the platform to reach the fruits if the bunches are hidden by the fronds hence nullifying the safety aspect. Smaller elevating devices have also been proposed by various manufacturers (Garbati Pegna *et al*, 2012) but none has succeeded in capturing farmers' confidence.

Aiming at addressing the mechanization problems of smaller or difficult farms, by providing a flexible and light machine for operator's access to the high parts of the palms, two Italian companies ERREPPI and CO.ME.T. developed Xiraffe, an off-road light aerial platform, easily adaptable to diverse operating conditions, ensuring safety and easiness for working even at considerable heights (fig. 2). This machine constitutes a novelty in this sector for its characteristics and its suitability to work in harsh conditions and could represent a rentable solution, also susceptible of further developments, for field operations at frond level, offering suitable and affordable specialized mechanization solution even to the medium and small sized farms.

This study analyses the performances of Xiraffe focusing on the harvesting operations; the investigation is based on data collected in 2017, during field trials in Medjool plantations in Jordan Valley (H.K. of Jordan); these trials, carried out on palms of different height and characteristics, aimed at comparing mechanized and traditional manual harvesting, which is still the most common method in the study area.

Figure 2. Xiraffe, a self-moving off-road light aerial platform for date palm cultivation.

CHAPTER ONE

1. DATE PALM

1.1 History and diffusion

Date palm (*Phoenix dactylifera* L.) is one of the oldest known fruit crop that has been cultivated. Because of the long history of date culture and the wide distribution and exchange of date cultivars, the exact origin is unknown (Chao and Krueger, 2007). However it is most likely originated from the ancient Mesopotamia area, where it was cultivated as early as 4000 B.C., since it was used for the construction of the temple of the moon god near Ur in Southern Iraq (Zaid and de Wet, 2002b). From its centre of origin, date cultivation spread throughout the Arabian Peninsula, North Africa, and the Middle East. The diffusion of date cultivation later accompanied the expansion of Islam and reached southern Spain and Pakistan (Chao and Krueger, 2007). Only in the last few centuries it was introduced to new production areas in America, Australia and many other regions of Africa (fig. 1.1.). Date cultivation has had a very important influence on the history of the Middle East and North Africa. Thanks to its capacity to grow and be productive in very dry and hot climate, it represented the main income source and staple food for local populations and have played significant roles in the economy, society, and environment of those regions (Chao and Krueger, 2007).

1.2 Ecology of the plant

Phoenix dactylifera L. can grow in very hot and dry climates, and is relatively tolerant of salty and alkaline soils. Date palms require a long, intensely hot summer with little rain and very low humidity during the period from pollination to harvest, but with abundant underground water near the surface. One old saying describes the date palm as growing with “its feet in the water and its head in the fire”. Such conditions are found in the oases and valleys (or wadis) of the date palm’s center of origin in the Middle East (Chao and Krueger, 2007).

The distribution according to latitude can be enclosed between 10° to 37° parallel for both northern and southern hemisphere, and to altitude flourishes from 392 m below sea level to 1,500 m above with an altitude range of 1,892 m (Zaid and de Wet, 2002b). Some cultivation can be also traced in the arid spot of tropical area (fig. 1.1).

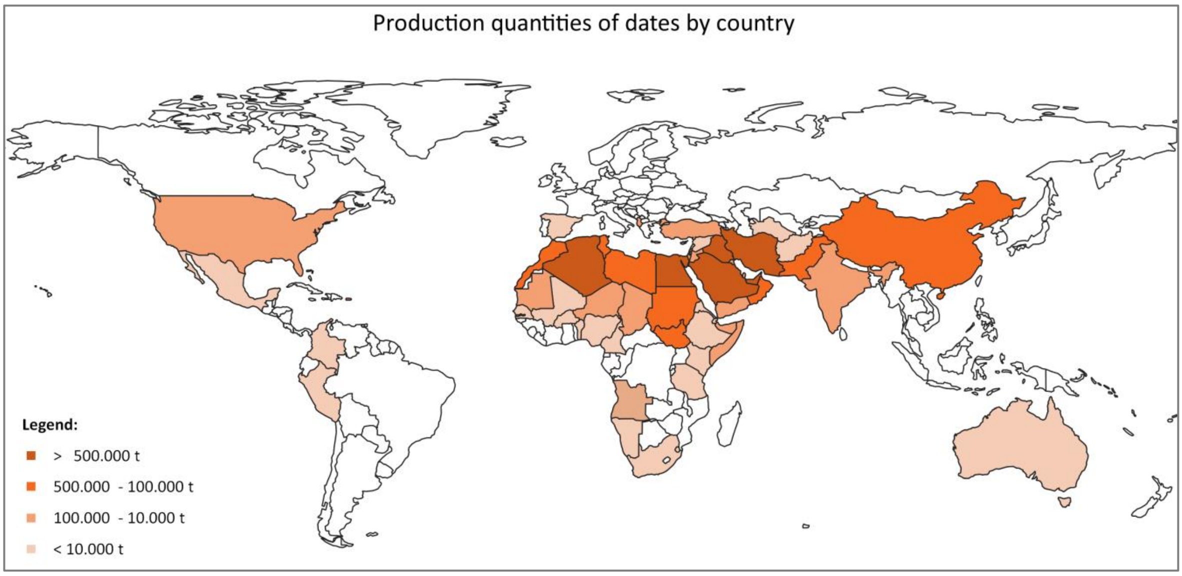

Figure 1.1. Distribution of date palm production in the world in 2016 (data source FAOSTAT, 2018).

The ideal temperature for the growth of the date palm, during the period from pollination to fruit ripening, ranges from 21 to 27 °C average temperature (Chao and Krueger, 2007). The zero vegetation point is 7°C, above this level growth is active and reaches its optimum at about 32°C (Zaid and de Wet, 2002c). The growth will continue at a stable rate until the temperature reaches 38°C/40°C when it will start decreasing, withstanding up to 50 °C and sustaining short periods of frost at temperatures as low as -5 °C. At -6°C pinnae margins turn yellow and from -9 to -15°C, leaves of medium and outside canopy will be damaged and dry out with poor quality on the fruit. If these low temperatures are maintained for a long period (12 hours to 5 days) all leaves will show frost damage and the palm will look as if it was burnt (Zaid and de Wet, 2002c). Date palm culture has mostly been developed in dry areas with winter rainfall which does not cause harm to the date fruits, but benefits the soils of the plantations by lessivating the deposited surface salt and avoiding the upward movement of salt from lower layers. The major damage caused by rain occurs when either the rain is early, or the dates are late in ripening. In fact, the last ripening stages, are the most sensitive since rain and associated humidity cause severe damage including rotting and fall-off of the fruits. Rain or cool weather occurring near harvesting is also inclined to delay ripening. It is worth mentioning that the amount of any particular rain is of less importance than the conditions under which it occurs (Nixon and Carpenter, 1978 in Zaid and de Wet, 2002c). A light shower accompanied by prolonged periods of cloudy weather and high relative humidity may cause more damage than heavy rain followed by clear weather and dry winds (Zaid and de Wet, 2002c).

For this reason, both rain and air humidity are two of the most important climatic requirements, especially during the pollination and maturity days, to produce good dates. At high humidity, fruits become soft and sticky, while at low humidity they become very dry. This phenomenon is strengthened when low humidity is coupled with hot and dry winds. Dry and hot winds cause a rapid maturation process leading to fruit desiccation and the appearance of a yellow or white ring at the fruit base (Zaid and de Wet, 2002c).

Compared to other plant species, the date palm shows no damage under windy conditions (Zaid and de Wet, 2002c). In fact, date palm can withstand strong, hot and dusty summer wind and consequently protects the other cultures by breaking the force of the wind and sheltering more susceptible vegetation (Dowson, 1982 in Zaid and de Wet, 2002c). In most date growing areas the latter part of the pollination season is usually characterised by severe hot and dry winds which dries out the stigmas of the female flowers. Cold winds disturb the pollen germination. It seems, therefore, that dry wind storms lead to a faster drying of the styles which shortens the time for the pollen to reach the ovule (Reuveni et al., 1986 in Zaid and de Wet, 2002c). The speed of the wind could also have an effect on the pollination efficiency; light winds are beneficial and favour pollination while high speed winds will blow away a great deal of the pollen, principally on palms found at the edges of the plantation, could also break the inflorescence's fruit stalk (rachis) and facilitate mites diffusion (Zaid and de Wet, 2002c).

Date palm needs high light intensity and two are the main threshold to evaluate the photosynthetic activity. The compensation threshold that reaches about 200 candles light, which not give a benefit to leaves because all sugars created will be consumed during respiration, and saturation threshold with a light intensity of about 5,000 candles light, where leaves reach the highest level of the transformation to convert the photovoltaic energy into carbohydrates (Al-Khafaji, 2013).

1.3 Botanical description

Date palm, belonging to the family of Palmaceae (Arecaceae), is a diploid (2n=2x=36), perennial, and angiosperm-monocotyledonous plant (Barrow, 1998 in Chao and Krueger, 2007) but polyploidy cases were reported with Iraqi date varieties (2n = 64) (Al- Salih and Al Najjar, 1987 in Al-Khafaji, 2013).

The botanical name, *Phoenix dactylifera L.*, is related to many different interpretations. One of these refers this to the mythological bird “Phoenix” by the laves shape of the plant and “dactylifera” from the Greek words *daktylos*, which means "finger", and *fero*, which means "I bear" (fig. 1.2) (Linné, 1734 in Zaid and de Wet, 2002a).

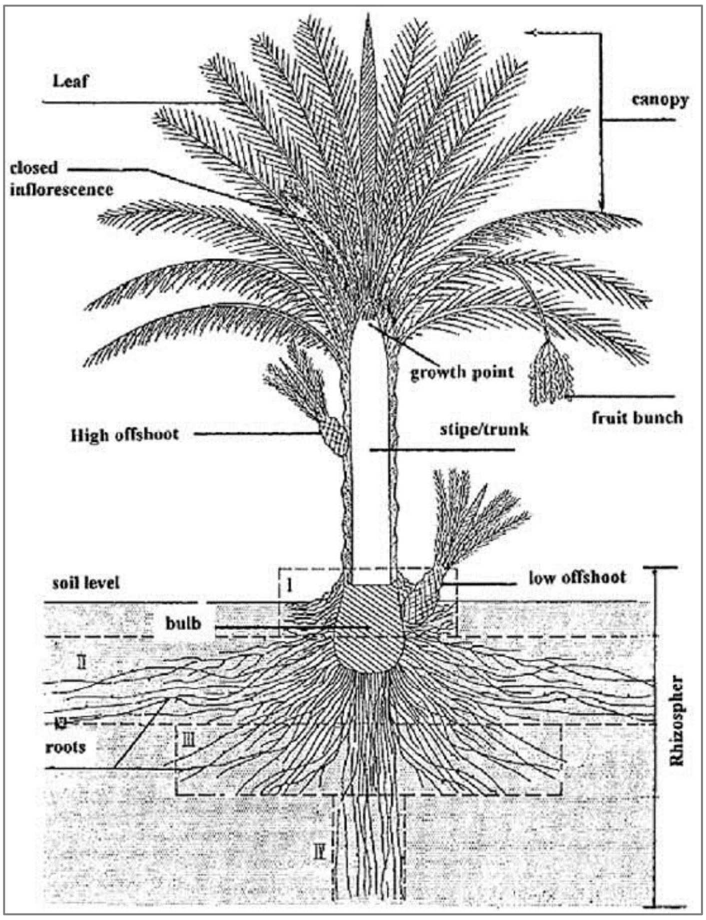

Figure 1.2. Diagrammatic construction of a date palm (Zaid and de Wet, 2002a).

1.3.1 Root

Being a monocotyledon, date palm has no tap root. Its root system is fasciculated and roots are fibrous. Secondary roots appear on the primary root which develop directly from the seed. These secondary roots produce lateral roots (tertiary roots and so on) of the same type with approximately the same diameter throughout their length (fig. 1.2). Roots can also grow from the trunk on the soil surface (Al-Khafaji, 2013). These roots are named aerial and can weaken the trunk for the cracks they produce to emerge from the basic frond’s armpit (fig. 1.3). In this case the naked part of the trunk must be covered with the soil in order to avoid this problem and to bury the aerial roots (Al-Khafaji, 2013). All date palm roots present pneumatics, which are respiratory organs (Zaid and de Wet, 2002a). Roots are found as far as 25 m from the palm and deeper than 6 m, but 85 % of the roots are distributed in the zone of 2 m deep and 2 m on both lateral sides in a deep loamy soil (Munier 1973 in Zaid and de Wet, 2002a).

 

Figura 1.3 and 1.4. Aerial roots with consequent weaken trunk (left) and branching phenomenon (right).

1.3.2 Stem

The date palm trunk, also called stem or stipe, is vertical, cylindrical and columnar of the same girth all the way up (Zaid and de Wet, 2002a). The girth does not increase once the canopy of fronds has fully developed. It is brown in colour, lignified and usually without any ramification although branching phenomenon may occur (fig. 1.4). Its average circumference is about 1 to 1.10 m. The trunk is composed of tough, fibrous vascular bundles cemented together in a matrix of cellular tissue which is much lignified near the outer part of the trunk. Being a monocotyledon, date palm does not have a cambium layer. Horizontal or lateral growth is ensured by an extra fascicular cambium which soon disappears, and which results in a constant and uniform trunk width during the palm's entire life. Vertical growth of date palm is ensured by its terminal bud, called phyllophor (Zaid and de Wet, 2002a).

1.3.3 Leaf

Depending on variety, age of a palm and environmental conditions, leaves of a date palm are 3 to 6 m long (4 m average) and have normally a life of 3 to 7 years (Zaid and de Wet, 2002a). They are formed by 120 to 140 leaflets per frond, entirely lanceolate, folded longitudinally and obliquely attached to the rachis (fig. 1.6). Their length ranges from 15 to over 100 cm and in width from 1 to 6.3 cm. The greatest width of the frond attains 0.5 m narrowing at the base and tip. The frond midrib or petiole is relatively triangular in cross section with two lateral angles and one dorsal. It is bare of spines on both sides, which vary from a few cm to 24 cm in length and from a few mm to 1 cm in thickness (fig. 1.5). The base of the frond is a sheath encircling the palm and it consists of white connective tissue ramified by vascular bundles (Dowson, 1982 in Zaid and de Wet, 2002a). As the frond grows upwards, the connective tissue largely disappears leaving the dried, and now brown, vascular bundles as a band of tough, rough fibre attached to the lateral edges of the lower part of the midribs of the fronds and unsheathing the trunk (Zaid and de Wet, 2002a). An adult date palm has approximately 100 to 125 green leaves, grouped in 13 nearly vertical columns, with an annual formation of 10 to 26 new leaves. Furthermore, leaves which are four years old are only about 65 % as efficient in photosynthesis per unit area, compared to leaves of one year old (Nixon and Wedding, 1956 in Zaid and de Wet, 2002a). Under good cultural conditions a leaf can support the production of 1 to 1.5 kg of dates (Zaid and de Wet, 2002a).

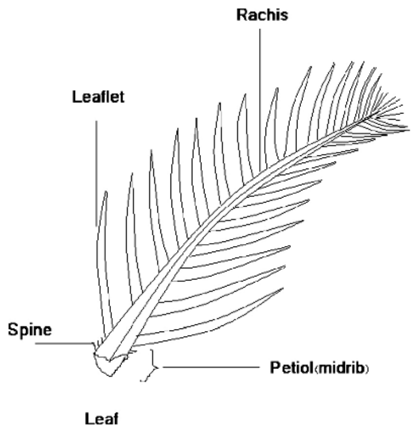

Figure 1.5 and 1.6. Date palm leaf (left) and schematic draw (right) (Zaid and de Wet, 2002a and Mirmehdi, 2014).

1.3.4 Inflorescence

Date palm is a dioecious species with male and female flowers being produced in clusters on separate palms (Zaid and de Wet, 2002a). In rare cases both pistillate and staminate flowers are produced on the same spike while the presence of hermaphrodite flowers in the inflorescence has also been reported (Mason, 1915 and Milne, 1918 in Zaid and de Wet, 2002a). Palms which carry both unisexual and hermaphrodite flowers are known as polygamous. The unisexual flowers are pistillate (female) and staminate (male) and they are born in a big cluster (inflorescence) called spadix or spike, which consists of a central stem called rachis and several strands or spikelets (usually 50 - 150 lateral branches). The inflorescence, also called flower cluster, in its early stages is enclosed in a hard envelope known as spathe which splits open as the flowers mature exposing the entire inflorescence for pollination purposes. The spathe protects the delicate flowers from being shrivelled up by the intense heat until these are mature and ready to perform their function (Zaid and de Wet, 2002a). Each spikelet carries a large number of tiny flowers as many as 8,000 to 10,000 in female and even more in male inflorescence (Chandler, 1958 in Zaid and de Wet, 2002a). The annual number of spathes born by a palm varies from none to about 25 in females and an higher number in males, but the average is a dozen for females and some more for males (Zaid and de Wet, 2002a). The male inflorescence is crowded at the end of the rachis, while branches of the inflorescence of the female cluster are less densely crowded at the end of the rachis. These characteristics allow the recognition of the inflorescence's sex before its opening (fig. 1.7 and 1.8). The male flower is sweet-scented and normally has six stamens, surrounded by waxy scale-like petals and sepals (3 each). Each stamen is composed of two little yellowish pollen sacs. The female flower has a diameter of about 3 to 4 mm and has rudimentary stamens and three carpels closely pressed together and the ovary is superior (hypogynous) (Zaid and de Wet, 2002a). On opening the female flowers show more yellow colour while the male ones show white colour dust, produced on shaking. The pollen sacs usually open within an hour or two after the bursting of the spathe. Only one ovule per flower is fertilized, leading to the development of one carpel which in turn gives a fruit called date; the other ovules aborted. The aborted carpels persist as two brown spots in the calyx of ripe fruits (Zaid and de Wet, 2002a).

Figure 1.7 and 1.8. Male (left) and female (right) flower of date palm (Zaid and de Wet, 2002a).

1.3.5 Fruit

Depending on the variety, environmental conditions and the technical care given (fertilisation, pollination, thinning, etc.), the characteristics of the fruit obtained vary tremendously (fig. 1.9 and 1.10). The date fruit is a single, oblong, one-seeded berry, with a terminal stigma, a fleshy pericarp and a membranous endocarp (between the seed and the flesh). The fruits take about 150-200 days from the pollination to the fully ripening stage.

Commonly a date palm tree lives up to 100 years and the fruiting starts 5-6 years after planting; the top production begins with the second decade of its life and continues to the age of 50-60 years (Zabar, 2012; Ibrahim, 2008).


Figure 1.9 and 1.10. Different dates varieties with the bunch (left) and dried in a market (right).

1.3.6 Seed

As with the fruit, seed characteristics vary according to variety, environmental and growing conditions. A seed's weight could range from less than 0.5 g to about 4 g, in length from about 12 to 36 mm and in breadth from 6 to 13 mm. The seed is usually oblong, ventrally grooved, with a small embryo, and with a hard endosperm made of a cellulose deposit on the inside of the cell walls (Zaid and de Wet, 2002a).

1.4 Dates ripening stages

We can count more than one hundred date palm varieties spread all over the world. But among all, some of the most famous are Barhi, Hayani, Medjool and Deglet Nour. Many differences can be noticed between these not only in the palm shape, but specially in the fruit characteristics like color, taste and harvest period. Are mainly these differences to justify their cultivation in different market or environment where each of them is most adapted. However, there are also many similarities among which the various stages for dates ripening. In fact, as well reported by Zaid and de Wet, 2002, the growth and development of date palm fruit involves several external and internal changes. These changes are often classified on the basis of change in colour and chemical composition of the fruit, as five distinct stages of fruit development, known in order as *Hababauk*, *Kimri*, *Khalal*, *Rutab* and *Tamer* (fig. 1.11).

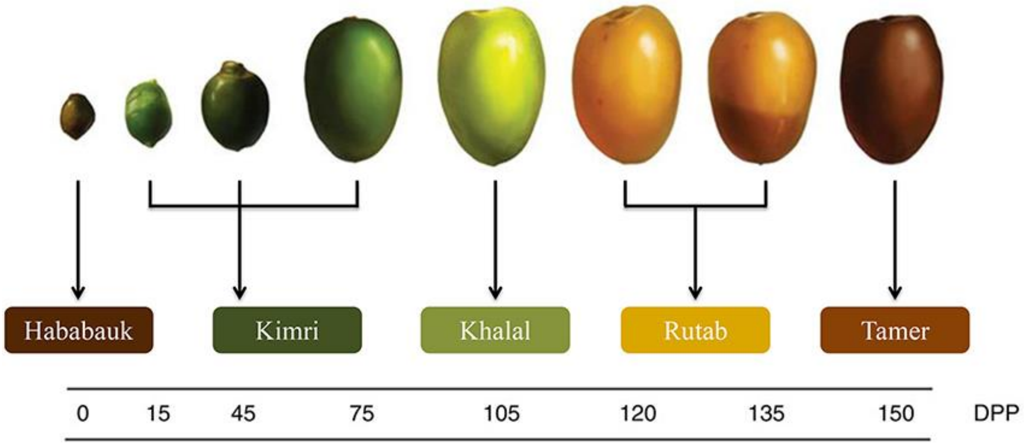

Figure 1.11. Different fruiting stages of date palm according to days post-pollination.

Hababauk (or *Hababouk*) stage: The first stage takes four to five weeks to complete and is characterised by the loss of two unfertilised carpels and a very slow growth rate. The fruit, completely covered by the calyx, is still immature and only the sharp end of the ovary is visible. Its average weight is 1 g and the size is about that of a pea (Zaid and de Wet, 2002a).

Kimri or green stage: This stage lasts from a small green berry to an almost full sized green date still not suitable for eating. It is characterized by a rapid increase in weight and volume by accumulation of moisture (85%), sugars, total solid and the highest active acidity (Barreveld, 1993 and Zaid and de Wet, 2002a). This is the longest stage of growth and development and lasts a total of nine to fourteen weeks, depending on varieties (Zaid and de Wet, 2002a).

Khalal or colour stage: The fruit is physiologically mature, hard ripe and the colour changes completely from green to yellow, red or scarlet depending on the variety. It lasts three to five weeks, date fruit reaches its maximum weight and size and the colour of seed changes from white to brown. The sucrose content increases, moisture content goes down (60% of the total weight) and tannins will start to precipitate losing its astringency (Barreveld, 1993). Some varieties, such as Barhi, are consumed in this stage, as they are very sweet, juicy and fibrous but not sour. However, *Khalal* dates must be eaten immediately after harvesting as they will keep for only a few days without cold storage (Zaid and de Wet, 2002a).

Rutab or soft ripe stage: This phase is characterized by a decrease in weight due to moisture loss, a partial inversion of sucrose into invert sugar and a browning of the skin and softening of the tissues. The moisture content goes down to about 35-40% and the dates at this stage are sold as fresh fruit (Barreveld, 1993).

Tamer (or *tamar*) also called full ripe stage or final stage in the ripening: This is the stage when the dates are fully ripe, the texture of flesh is soft and they completely change the colour to dull brown or almost black. The skin in most varieties adheres to the flesh, and wrinkles appears as the flesh shrinks. At this stage, the date contains the maximum total solids and has lost most of its water to such an extent (20-24 %) that it makes the sugar water proportion sufficiently high to prevent fermentation. This is the best condition for storage. At the *tamer* stage, the fruits on a bunch do not all ripen simultaneously, but over almost a month requiring three to four harvest sessions (Zaid and de Wet, 2002a).

1.5 Utilization of date palms

As a result of the long history of cultivation and utilization, almost every part of the date palm can be used for some purpose (Barreveld, 1993 in Chao and Krueger, 2007). Some of the most common purposes are hereby summarized:

The trunk and wood of date palms can be used for local furniture, to erect the houses, roofs, timber and fuel (fig.1.12). Fiber, from the trunk and leaves, is perfect for bags, baskets, camel saddles, cords, crates, fans, food covers, furniture, mats, paper, ropes, trays, and twine (Chao and Krueger, 2007). Dried bundles of leaves, can be made into shades, roofs, separating walls, and enclosures. By leaves ribs small fishing boats (called ‘‘Shasha’’) or fishing traps are built while fuel is obtained from the base of the leaves and fruit stalks (fig. 1.13).

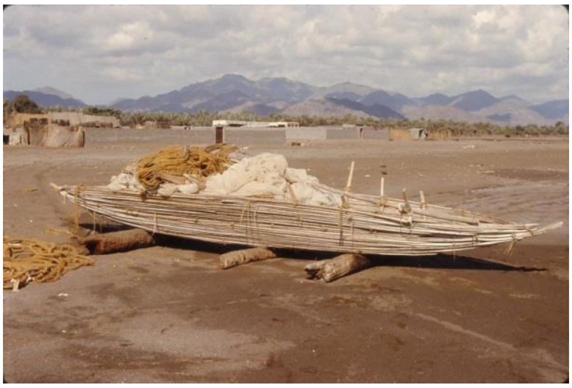

Figure 1.12 and 1.13. House made by date palm elements (left) and "Shasha" boat (right).

Date palm flour can be obtained from the pith of the palms. Terminal buds (palm heart) can be eaten as a salad or as a cooked vegetable (Chao and Krueger, 2007). A coffee-like product is made from date seeds by drying, roasting, and grinding them in a similar way to coffee beans, to produce caffeine-free beverage. It’s also possible to get an high nutrient value flour which is mixed with the traditional wheat one to cook breads or other products. Date seeds can be also used to feed the livestock or strung as beads for decoration and oil from date seeds can be manufactured into soap. In India, the gum or exudate of dates is used for treating diarrhea and the roots are used to treat toothache. Groves of date palms are important environmental niches for local wildlife and play a central role in the desert ecological system and the control of desertification (Chao and Krueger, 2007). But is the fruit the most known product. Dates are especially delicious as a fresh fruit but they are also used as a component in food preparations like sweets, snacks, confectionery, baking products, institutional feeding and health foods. Derived products are also common like date paste, juice, syrup, liquid sugar (Saccharin as a low calorie sweetener for soft drinks), protein yeast, vinegar and fermentation products (wine, alcohol, organic acids, etc.). It is one of the best sources for essential minerals (Ca, P, Fe and K) in addition to proteins and amino acids (table 1.1).

Fruit (100g)	KJ/Kcal	Sugars (g)	Proteins (g)	Fibers (g)	Minerals (mg)			
					Ca	P	Fe	K
Date (Medjool)	1160/287	66.47	1.81	6.70	64.00	62.00	0.90	696.00
Mango	250/60	13.66	0.82	1.60	11.00	14.00	0.16	168.00
Banana	371/89	12.23	1.09	2.60	5.00	22.00	0.26	358.00
Orange	197/47	9.35	0.94	2.40	40.00	14	0.10	181.00

Table 1.1. Nutritional value of dates compared with other fruits per 100g weight (USDA 2018).

Date fruit also have many medicinal uses even if some of these are not scientifically demonstrated yet. They can be used as an astringent for treating intestinal problems, treatment for sore throat and colds, relief of fever, cystitis, edema, liver, and abdominal problems, to counteract hangovers and many others.

1.6 World production

In the last years, the date palm cultivation has reached considerable levels of production and cultivated area, reconfirming itself as an important agricultural fruit crop for the countries of the desert and subtropical area of the northern hemisphere (Battaglia, 2011). In 2016 the world production reached 8,460,443 t, while the harvested area has expanded to 1,353,159 ha (FAOSTAT, 2018).

The production is mainly situated in the Islamic regions of West Asia and North Africa where date fruit have great cultural and traditional significance. According to FAOSTAT, 2018, the top-ten dates producing countries in 2016 were Egypt (1,694,813 t), Islamic Republic of Iran (1,065,704 t), Algeria (1,029,596 t), Saudi Arabia (964,536 t), United Arab Emirates (671,891 t), Iraq (615,211 t), Pakistan (494,601 t), Sudan (439,120 t), Oman (348,642 t) and Tunisia (241,000 t) (fig. 1.14).

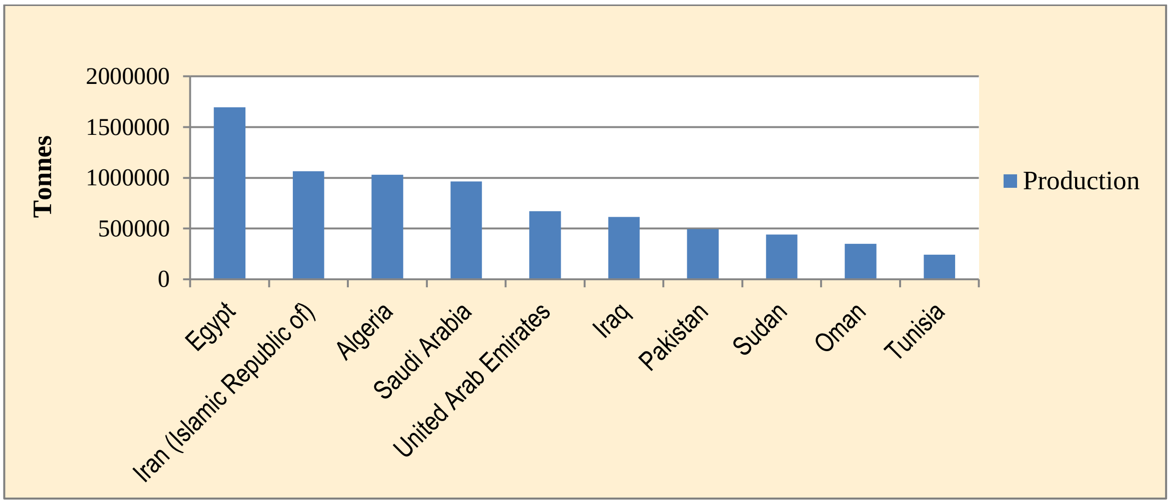

Figure 1.14. Top 10 dates producing countries (FAOSTAT, 2018).

Another important centre of dates palm production is in Israel and the United States (California and Arizona). The average quantity (total tons) is much lower but the quality is high and commands a price advantage for export, especially for Medjool variety (Chao and Krueger, 2007).

The top five date-exporting countries in 2013 were Pakistan (169,159 tons), Iraq (144,607 tons), Tunisia (105,803 tons), Saudi Arabia (99,770 tons) and Islamic Republic of Iran (93,030 tons) (FAOSTAT, 2018). But between these, is Tunisia the country with the highest export prices thanks to the first quality products, selection of specific varieties (Deglet Nour) and good trade relationship with Europe, France in particular. In fact, Europe is the world import leader of dates palm in terms of money value and the second one, after India, in terms of quantity (Battaglia, 2011).

In general, the highest consumption of dates is during Ramadan but, in the last decades, an increment in market demand is registered during the Christmas holidays in Europe and United States, where Medjool and Deglet Nour are the most requested varieties. However, thanks to the good storage properties, dates are available and well traded for all the year. Production exceeds or low quality fruits can be utilized for industrial purposes.

CHAPTER TWO

2. DATE PALM CULTIVATION

2.1 Cultural practices

The average economic life of a date garden is 40 to 50 years, but some are still productive up to 150 years (Chao and Krueger, 2007). This happen if ideal conditions occurs making cultural practices fundamental to ensure the long term success of the plantation.

2.1.1 Ground level operations

These operations are not influenced from the height of the plant and are not always specific of date palm cultivation. In some case, ground level operations are influenced by intercropping with other fruit trees (citrus, pomegranates, olives, grapes, etc.) or arable crops (alfalfa, barley, beans etc.). This is traditionally practiced in many of the main production areas, where without the shade provided by the date palms other crops cannot grow.

2.1.1.1 Land preparation

The first of these operations involve land preparation which has the purpose to provide the necessary soil conditions which will enhance the successful establishment of the plants. A situation with high water holding capacity, good drainage and sufficient room for root development is desirable (Nixon, 1959). Previously, the general assumption for a commercial date plantation was to use a plant spacing of 10 × 10 m (100 palms/ha. It has, however, changed over time and a plant spacing of 9 × 9 m or 8 × 8 m, is used in modern plantations (Klein and Zaid, 2002). Along the years, tillage operations may be required to facilitate the irrigation, workers access and maintain good and fertile soil conditions.

2.1.1.2 Propagation

There are three methods for date palm propagation which are well described by Chao and Krueger, 2007. The most common method is the vegetative propagation of offshoots, which ensures the genetic identity of maternal varieties. Offshoots develop from axillary buds on the trunk and after 3 to 5 years of attachment to the parental palm, produce roots and can be removed and planted (fig. 2.1 and 2.2). The second propagation method is to use chance seedlings from sexual crosses. Seedlings are not identical to the maternal trees and not uniform genetically, varying greatly in their production and fruit quality. About 50% of the seedlings are male although they cannot be identified until trees began to flower after 4 to 5 years. Production and fruit quality from seedling-derived groves are greatly reduced compared with groves developed from offshoots. The third date propagation method is through tissue culture. Tissue culture propagation of date palms from shoot tips through either embryogenesis or organogenesis was first developed in the 1970 to 1980s. Organogenesis can be achieved using auxiliary buds and apical meristems, whereas embryogenesis can be done through callus stage from various meristematic tissues like shoots, young leaves, stem, rachilla, and so forth. However, one of the main problems with tissue culture propagation is somaclonal variation (off types) which may exhibit several abnormal phenotype variations (Chao and Krueger, 2007).

Figure 2.1 and 2.2. Date palm offshoots (left) and the cutting from the parental palm (right).

2.1.1.3 Irrigation

Immediately after transplanting, the palm should be irrigated to limit transplant stress and to avoid the formation of air pockets around the roots. From now and for the next years, a frequent irrigation schedule is to be followed to allow sufficient water supply to the dates palm. The irrigation frequency, is soil and environment type dependent with the highest needs in case of very sandy soils in really hot and sunny areas. An insufficient amount of water in dry season will affect the rate of tree growth and decreased the moisture content of fruits (Reuther and Crawford, 1945 in Chao and Krueger, 2007). Flood irrigation is the oldest and still most used form of irrigation but for new plantation the drip one is preferred now (Abdul-Baki et al., 2002 in Chao and Krueger, 2007). Many growers like to reduce or withhold irrigation during the harvest season. This may be done to make the garden accessible at all times, to promote the drying of some soft dates, or to reduce fruit drop in humid weather (Nixon, 1959).

2.1.1.4 Fertilization

Even if date palm is a strong and well adapted plant able to grow in soils containing more alkali or salts than many other plants will tolerate, some help by fertilization should be needed. Among the many different fertilization schedule, interesting is the one purposed by FAO (Klein and Zaid, 2002) which suggests fertilization programs according to the lost quantity of nutrients per year, supposing 121 palms per hectare (Table 2.1 and 2.2)

Nutrient	Losses/Palm/Year (g)	Losses/ha/year (kg)
Nitrogen (N)	350	42
Phosphorus (P)	90	11
Potassium (K)	540	65

Table 2.1. Average nutrient losses.

Nutrient	Application/Palm/Year (g)	Application/ha/year (kg)
Nitrogen (N)	650	78
Phosphorus (P)	650	78
Potassium (K)	870	104

Table 2.2. Average world-wide application.

Manure has traditionally been used in date production, but in many instances inorganic fertilizers are used. Many producers, even in industrialized production, consider manure to be superior to inorganic fertilizer (Chao and Krueger, 2007).

Between the ground level operations, we may consider also the waste management (old leaves, etc.) and the transport of the material within the plantations.

2.1.2 Crown level operations

A part the common agricultural practices like land preparation, irrigation and fertilization, date palm is characterized by many specific operation crucial for the success of the production. These usually require access to the crown of the tree, and in old trees reaching tens meters of height, this can be challenging and dangerous (Chao and Krueger, 2007). It is considered that each palm must be climbed 10 to 18 times per year to carry out many operations. The crown of the tree needs to be accessed for pollination, bunch tie-down, fruit thinning, covering, harvesting, pruning and dethorning.

2.1.2.1 Pollination

Date palms are dioecious so the male and female flowers are borne on separate palms. Date is wind pollinated in nature, but insect pollination is possible (Chao and Krueger, 2007). Even when male and female palm trees grow in the same orchards, pollination is not guaranteed (Al-Khafaji, 2013). The pollen from different male cultivars may have different effect on the production and quality of the fruits. Incompatibility or partial incompatibility between different female and male cultivars is common but not well understood (Chao and Krueger, 2007). The male/female ratio in a modern plantation is 1/50 (2 %) (Zaid and de Wet, 2002d). Pollination of 60% to 80% of the female flowers results in adequate fruit set (Chao and Krueger, 2007). The most common technique of pollination is to cut the strands of male flowers from a freshly opened male spathe and place two to three of these strands, lengthwise and in an inverted position, between the strands of the female inflorescence (Zaid and de Wet, 2002d). This should be done after some pollen has been shaken over the female inflorescence (Dowson, 1982 in Zaid and de Wet, 2002a). Using fresh male strands, the number required for pollinating a female spathe may vary from 1 to 10 depending on variety. Another interesting possibility is the mechanical pollination developed in USA and Israel, where labour is expensive and not always available. It consists of pollinating freshly opened female spathes from the ground by the help of a pressurized system. In order to accommodate the palm height and also to direct the pollen delivery tube near the bloom area of each palm, some machines are equipped with an aerial platform (Zaid and de Wet, 2002d).

2.1.2.2 Bunch tie-down

After pollination, bunches are often tied to the leaf stalks to support the weight of the fruit. With most commercial date varieties, after the pollination season, the bunches are pulled downwards through the leaves, gently enough not to break any of the strands, and the bunch fruit stalk is tied for support to the midrib (leaf rachis) of one of the lower leaves to avoid breaking. This operation is executed when the fruit stalk is fully extended (long enough) but still flexible to permit some of the curvature to be distributed, so that the base will not take all the stresses. This also makes the bunch easily accessible for thinning, bagging and/or pesticide application. (Zaid and de Wet, 2002d).

2.1.2.3 Fruit thinning

Fruit thinning is sometimes practiced in date cultivation. Fruit thinning is used to decrease alternate bearing, increase fruit size, improve fruit quality, advance fruit ripening, and facilitate bunch management. Fruit thinning can be carried out three ways: removal of entire bunches, reduction in the number of strands per bunch, and reduction in the number of fruit per strand. Cultivar, climate, and cultural practices influence the appropriate levels of fruit thinning (Zaid and de Wet, 2002d).

2.1.2.4 Covering

Bunches of dates are usually covered with brown craft paper, white paper, or cotton or nylon mesh bags. Bagging can protect fruit bunches from high humidity and rain, minimize damage from sunburn, and decrease losses from birds and insects (Nixon and Carpenter, 1978; Zaid and de Wet, 2002d). The bag will also facilitate the collection of fallen ripe fruit.

2.1.2.5 Pruning and trunk cleaning

Pruning in date palm is in general the removal of only dead, or nearly dead fronds and their bases. Depending on variety and cultural conditions, date palm leaves can remain alive for at least seven years with a maximum activity during the first year and an ultimate decrease in their photosynthetic capacity. As the leaves do not drop of their own accord, they must then be cut off. Removing the leaves up to about the point where the lower ends of most fruit bunches are exposed is highly recommended for adult full bearing palms. Pruning is mainly practiced after fruit harvest. During the pruning operation, unwanted offshoots should also be removed to foster growth of those that are retained on the palm for propagation, to make access to the palm easier and to promote growth and bearing of the parent palm (Zaid and de Wet, 2002d).

2.1.2.6 Dethorning

Another important pruning process is the removal of spines, also called thorns. It is advantageous to annually remove spines from the base of new leaves in order to facilitate pollination and handling of fruit bunches. Cut thorns themselves are a source of some danger, because they lodge in leaf bases on the soil where they persist as a hazard. Date spines are usually removed from the new growth of fronds in the crown of the palm just before the pollination season to allow easy access to the date spathes as they emerge. If the palms have been dethorned the previous year, the new growth will be 2 or 3 rounds of fronds, each round developing 13 new leaves, a total of about 26 to 36 fronds to be dethorned (Zaid and de Wet, 2002d).

2.1.2.7 Harvesting

Once ready, the dates need to be collected and delivered to the ground level for the next transport and post-harvest operations. Time of harvest is based on date fruit's appearance and texture (related to moisture and sugar content). Proper timing of harvest reduces incidence and severity of cracking or splitting of dates, excessive dehydration, insects and microorganisms infestation. In northern hemisphere dates are harvested in August at the *khalal* stage or in September to December at the *rutab* and *tamer* stages. In the southern hemisphere, generally harvesting takes place from February to April. This alternation in production periods allows to have fresh dates throughout the year, especially for those varieties with high commercial interest such as Medjool and Barhi. Harvesting must be faultless and clean, since it significantly affects the rest of the process (packing and marketing). Harvesting the fruit straight into containers suitable for transport to the packinghouse prevents the infection of the fruit by the soil under the palm and ensures that the fruit arrives in good condition, and that it is not crushed (Glasner, 2002).

In general where possible and needed, other additional practices, as plant inspection and fumigation, are operated at the crown level. This is very important for the early detection of red palm weevil (Rhynchophorus ferrugineus) where the continuous monitoring is one of the main solution for the prevention of further spread (fig. 2.3 and 2.4).

Figure 2.3 and 2.4. Red palm weevil (left) and heavy damages caused in a plantation (right).

2.2 Mechanization status in date palm harvesting

In most of date palm cultivation, operations at the crown level are still performed manually. Here, skilled and trained workers climb up the palm with no protection or with the support of belts or straps or of other people piled up on each other’s shoulder. Where possible, long wood or aluminum ladders may be used but considerable skills and effort are still required and the danger to carry out these operations remain high (Opara, 2003 in Garbati Pegna, 2008, Nourani, 2016). This is particularly true when palm height is over 6-8 m, causing many victims yearly or the abandoning of the higher palms (Garbati Pegna, 2008). Date growers almost always stop watering those palms, causing them to die or lack of production, that reach a height which is considered unsafe for climbing (Akyurt, 2002).

Among all, harvest is the main and most important operation. But in these conditions, as the palm tree grows taller, harvesting the dates becomes more difficult and more costly. The palm can grow up to one meter every year (depending on variety and the intensity of treatment) quickly improving the difficulties and risks of the operations at crown level and consequently affecting the timeliness of agricultural practices. Because of this, the number of skilled workers is decreasing annually and the cost of labor is predicted to raise.

Along the years, several machines, derived from industrial and building sector, have been developed to facilitate harvest operations. But the high costs and problems to their adaptation to the different conditions of the plantations has limited their utilization and diffusion. Although attempts are being made to harvest the fruit by the help of machine, a specific mechanization support in this sector is still missing.

2.2.1 Traditional harvesting methods

In many producing countries of the world, which have been planting date for centuries, date is mainly harvested manually. Operators carry to the frond level a knife and possibly other tools such as a rope, a bucket and a pulley equipped with a hook (fig. 2.5 and 2.6). If they are not equipped with these tools they drop the fruit onto the ground (Shamsi, 1998).

Figure 2.5 and 2.6. Traditional manual harvest by cutting of bunches (left) or fruit selection (right).

Depending on the variety and climate, dates are hand harvested using one of the following methods:

a) Bunch cutting is used where all fruits on a bunch ripen at the same time. The worker cuts the bunch, ties the rope to it and lowers it to the ground. If the fruits are dry and if they do not have the rope they drop the bunch from the tree (Shamsi, 1998).

b) Bunch shaking is used when all fruits do not ripen at the same time and where shaking the bunch does not seriously affect the quality of the remaining fruit. In this case the tree is harvested several times during the season. If the bunches are covered, dates will be collected inside the bag and consequently placed in a bucket lowered to the ground with the help of a rope. This is a common procedure in plantations where valuable varieties are cultivated. In other circumstances the worker shakes the bunch with his hand or a stick, with other operators holding a circular cloth around the tree on the ground to collect the falling fruits. With this method many fruits may be damaged because of the impact shock (Shamsi, 1998).

c) Hand picking is used for those varieties which have fruits that are sensitive to vibration. Workers pick mature fruits one by one and collect them in a small basket. When the basket is full it is lowered to the ground (Kashani 1992 in Shamsi, 1998).

3.2.2 Mechanized harvesting methods

A major change that has taken place in U.S. date cultivation, under the impact of increasing labor costs and ever-increasing height of the palms, has been the mechanization of cultural practices, and in particular the timing and method of harvesting (Barreveld, 1993 in Akyurt, 2002). During the 1940's and 1950's a few growers in the US built large tractor–pulled harvesting towers which eliminated the need for ladders. The towers, however, were expensive. Starting with 1960, the use of truck-mounted hydraulic crane-like man-positioning machines was tried, to move workers from palm to palm. Neither attempt provided a significant increase in worker productivity (Brown, 1983 in Akyurt, 2002). Despite these observations, scarcity of labor was such that by 1966, 80% of the date crop in the US was being harvested mechanically by the use of these devices (Brown, 1983 in Akyurt, 2002). The harvesting system was owned by grower cooperatives. Each grower paid a fee for having a crew, hired and trained by the cooperative, harvest his fruit.

With the scope for possible mechanization of date farming a variety of field machinery was developed during the past twenty years. Nowadays, various types of harvesting machine are available, most of which are similar in principle and way to work (Akyurt, 2002). They are typically self-propelled or trailed machines equipped with a boom and platform to lift a worker up to the tree crown (Shamsi, 1998). However, even machines with different characteristics are available in the market. Examples of these systems are as follow:

a) Large "U" shaped aerial platforms mounted on hydraulic telescopic boom lift. This system allows many operators to work in elevation at the same time (fig. 2.7 and 2.8). It's possible to reach all the bunches of dates without any additional movement of the platform. The machine is fully controlled by the operator in the platform. This is one of the most common machines available in date palm plantations. The high weight of the unit (up to 10 tons) guarantees to carry up to 800 kg at the basket level at a maximum height of 21.5 m. Power outlets sources are even available to allow the use of different tools in elevation to perform different operations. Its demonstrated that this machine is much faster, safer and easier than hand harvesting (Shamsi, 1998).

Different but similar solutions are based on tractor lifting power platforms. In this case, the tractor forklift will support the metal platform along the various operations up to an average height of 12 meters.


Figure 2.7 and 2.3. Large "U" shaped aerial platform.

b) Another solution is represented by a vibrating head based system that can harvest the fruits by shaking the tree trunk. A roll-out canvas catching frame is commonly used for collecting the fruit (fig. 2.9 and 2.10). This method is only suitable for those varieties of dates whose fruits on a bunch do not ripen at the same time (Shamsi, 1998).

 

Figure 2.9 and 2.10. Palm stem shakers.

c) Tree climbing machines were also designed for a specific use in date palm cultivation. Based on slider mechanism and a grip force on the stem, they can climb up the operator to the frond, but these devices are not suitable for most date varieties and they still need many improvements (Shamsi, 1998). In fact, this mechanism is not suited to move on uneven surface of the date palm and has problems to carry variable and heavy weight. For this reason these machines have not been used commercially to harvest dates, but mainly as prototype for further studies.

The newer trend of utilizing forklift-manipulated tall platforms seems to offer a more economical and realistic approach to the issue of mechanization offering good level of safety and efficiency. Nevertheless the machines which have been designed so far are not suitable for most of the date groves for the following reasons:

- The large size and heavy weight may affect its maneuverability and impact on the plantation environment and consequent difficulties to adapt to the different farm environments (not always regular tree spacing, intercropping, etc.);
- There are many irrigation channels and borders which machines cannot pass over easily;
- The elevation of the harvesting system is not always sufficient for the tallest plants;
- High purchase prices and maintenance costs (Shamsi, 1998 and Akyurt, 2002).

Changing the planting technique to have trees in rows or the reduction in the number of irrigation channels is suggested. However, these conditions can be only found in large specialized plantations where valuable varieties are cultivated to have a fast repayment of the investment and to take advantage of this equipment, while medium and small sized farms, or the ones where the profit is not so high, still work in the traditional way.

For this reason new machines should be developed and light mechanization is becoming more important year by year. This because machine for date palm operations can be developed much easier and a lower prices will facilitate the access to all the types of farm to the utilization of mechanization.

CHAPTER THREE

3. STUDY AREA

3.1 Location and Topography

The Jordan Valley (Arabic: ال غور , Al-Ghor) forms part of the larger Jordan Rift Valley. This region is the lowest depression on earth (with the Dead Sea at 419 meters below sea level) and includes the Jordan River, flowing through the Jordan Valley, which is considered the food basket of Jordan. The topographic nature of the area has the typical rift valley characteristic with drastic drops in elevation over short distances from the edges of the valley, and a more gently decline closer towards the Jordan River (Kool, 2016).

The tests were carried out in three different farms, all located within 1 km along the Middle Jordan Valley, in the municipality of Ma'addi, Al-Balqa governorate, in an area at about 40 km North of the Death Sea and 40 km West of Amman (GPS coordinates: 32° 4' 23'' N and 35° 35' 11'' E) with a mean elevation of 270 m below sea level.

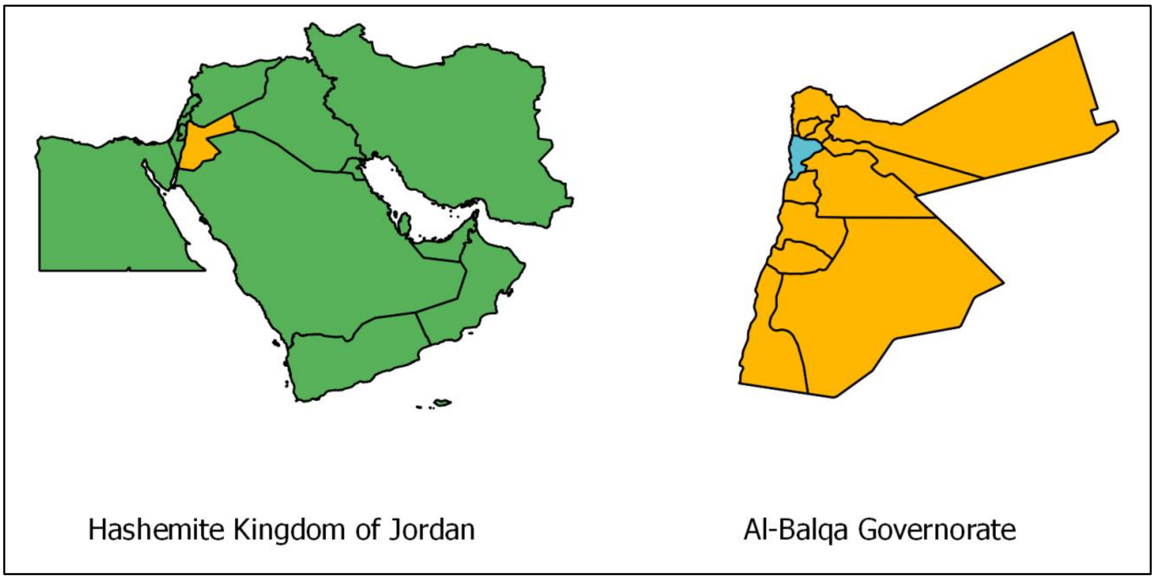

Figure 3.1. Localization of the study area.

3.2 Agriculture

Jordan is one of the most food dependent countries in the world, importing 90 % of its needs and 80 % of its foodstuffs. This dependence is mainly due to structural reasons, as Jordan is the fourth most water-deficient country in the world, with 147 m^3 of water per capita in 2010, but also to political issues, forcing to control the water distribution in the agricultural sector (Ababsa, 2014). Unlike Egypt and Syria, Jordan did not undergo agrarian reform. Large landowners managed to increase production by means of mechanization and by replacing the Jordanian work force with Egyptian migrants (Ababsa, 2014). Approximately 261,000 ha, or 2.7 % of Jordan's land area is arable and it is self-sufficient for mostly of vegetables as tomatoes, cucumber, eggplants and squash. Greenhouses are commonly used Agriculture is primarily practiced in two distinct agro-climatic regions:

a) The predominantly rainfed highlands, which produce mainly wheat, barley and some pulses, in addition to olives, grapes, almonds and other stone fruits;
b) The more intensive, irrigated farms in the Jordan Valley and southern Ghors, which produce fruits and vegetables for the local market and export (Ababsa, 2014).

Due to high temperatures and its location below sea level, Jordan Valley is the most important area for agricultural production, especially for winter vegetables. The average annual rainfall varies from over 500 mm per year in the north part to less than 100 mm in the south close to the Dead Sea. Because of the high temperatures and dry conditions the average annual evaporation is high, varying from 2150 to 2350 mm per year. Then, the high levels of salinity limit the utilization of ground water for both domestic and agriculture applications increasing the demand of water from external sources (Marie, 2001). This took to the spread of systems for saving water as the drip irrigation one.

3.3 Date palm cultivation in Jordan

This situation makes farming in the area very difficult and very expensive. The low amount of arable land increased the price of the plots (especially the ones in leasing) and the environment conditions force to make heavy utilization of supports, such as fertilizers, to have acceptable yields. This is particularly true in Jordan Valley where any production is based on relevant use of irrigation and fertilization. These drawbacks make agriculture very selective allowing the spread of a few types of crops. Greenhouse is the most common method for horticulture production but also citrus, grapes, pomegranate and palms are well established. Especially date palm production is growing and becoming more interesting year by year. In Jordan, the estimated area planted with date palm is about 3500 ha most of which in Jordan Valley, where Medjool and Barhi are the most cultivated varieties. Especially Medjool palms found a favorable environment where in recent years, the good production and the high quality of the fruits appreciated worldwide, increased the market demand and consequently the cultivation surface in this area.

3.3.1 Medjool

Among hundreds varieties of *Phoenix dactylifera* L., one of the most famous and worldwide marketed is the Medjool. Referring to its origin, in Arabic Medjool means "Unknown", but it's considered as originating from Morocco, where it was formerly reserved only for Moroccan royalty and their guests. In the 1920's date palms in Morocco were threatened with extinction by *bayoud* disease (*Fusarium oxysporum forma specialis albedinis),* so to save this variety, eleven date palms were sent to the USA. Nine of the eleven palms survived and are responsible for the millions of Medjool Dates that can be found in the world (Di Matteo, 2009). Six of these are still standing (and producing) in the Yuma date gardens and are affectionately referred to as the "Big Six" (fig. 3.2). Nowadays, because of its high commercial value, it is one of the most well-known and spread variety all over the world, especially in those countries where date palm cultivation is not an ancient and historical tradition.

Figure 3.2 and 3.3. The "Big Six" (left) and Medjool at different stages (right).

3.3.1.1 Plant characteristics

The trunk is medium size and may produce up to 20-25 offshoots per palm during its entire productive life. The leaves, dark green at early age, are short-medium length (3.5-3.8 m), and are organized with little curvature. The inflorescence is characterized by a short orange base with a large number of spikelets, with 50 to 60 flowers each. The bunches are orange-yellow in color short to medium size but thick. For this reason, if not properly supported, could be broken when bearing heavily. The fruits are very large (20-40 g) with an oval shape (50 mm long and 32 mm large) (Zaid and de Wet, 2002a). Irregularities in shape are common and are associated with ridges on the seed. They appear yellow-orange with clear dark red strips at *khalal* stage, *amber* at *rutab* and transparent dark brown to black at *tamer* (figure 3.3). Mature fruit color is related to the climate and growing conditions. The skin is irregularly wrinkled, shiny at the peak and dull at the lower part. Skin is medium thick and tender, tied to the flesh, but at *tamer* stage it shrinks. The flesh is firm, meaty and thick, brownish amber, translucent with practically no fiber around the seed and an ideal moisture content of 20-26%. The seed (1.5 g) is brown color darker at the end. On each side of the seed there is a protrusion forming a "wing shape" that is typical of Medjool and different from all other varieties (Zaid and de Wet, 2002a).

3.3.1.2 Special treatments

Medjool yield is around 80-120 kg per palm but to achieve large and jumbo sizes dates, the number of fruits per spikelets, bunches and the yield per palm must be monitored by the grower. Since the market demand is for large fruit (over 20 g) about 30 is the number of spikelets suggested per bunch and around 10 the number of fruit per spikelet (Zaid and de Wet, 2002a). The number of fruits per spikelet is mostly reduced by hand thinning which is done 3-4 weeks after pollination, when the dates are at 1 to 1.5 cm in size. At the time of harvest, 300 fruits are obtained per bunch with an average weight of 20 g per fruit. An adult palm bearing 10 to 12 bunches, will hence yield 60 to 72 kg of high quality Medjool dates and damages by pressure from adjacent dates born on the same strand will be reduced (Zaid and de Wet, 2002a).

Medjool is classified as a soft date and as an early ripening variety. The color ranging from light to dark brown is also affected by environmental factors. Since it is a high valuable crop, in most large and specialized plantations to make harvesting easy to handle, the worker is brought within reach of the bunch on a platform. Each bunch is then shaken gently to remove only ripe fruit. Basing on farms purposes, the best stages for harvesting is from a late *rutab* to the *tamer* one. The Medjool fruit in fact, falls off easily at these stages and the bunch is therefore wrapped up in a shade net or a cloth bag. The cover is open at the bottom and the ripe fruit is picked carefully from underneath through the openings, and placed on trays (Glasner, 2002). This type of harvesting is very labor-intensive and costly; however at present the high price obtained by this fruit justifies the process. Every bunch is harvested according to its state of ripeness, but it is important (especially in a hot climate) to begin when the ripe fruit is still soft; checking the fruit every week makes it possible to harvest in an optimal condition, and prevents the fruit from being attacked by pests (Glasner, 2002). This because many fruits fall from the bunch without the calyx, leaving a hole at the base of the date before drying is completed. Through this hole, fermenting beetles and fungi may enter the fruit and that causes the fruit to sour. In general, little damages are caused by rain. Fruit quality however, is very sensitive to temperature and humidity (Zaid and de Wet, 2002a). Both low and high extremes are not suitable for achieving high quality fruits. Drying takes place on trays in one layer; spread out in the sun or on platforms or in drying ovens, depending on the climatic conditions at the time of harvesting and on technological solutions (Glasner, 2002).

Two are the main non-pathogenic defects typical to Medjool:

a) Loose skin: During drying, on the palm and after picking, as the flesh loses water, the skin tends to separate from the flesh. Loose skin is mainly the result of growing and habitat conditions. It is not affected much by the naturally or artificially drying process. Loose skin is an aesthetic defect rather than a taste defect and fruit with more than 20 to 25 % loose skin are graded as Class II.
b) Sugar crystallizing: A common problem with loose skin fruit, mainly where the skin is broken, is that aromatic sugar crystals are formed on the flesh and under loose skin. Sugar crystallizing is more common in fruit with high moisture content at harvest. Again this is an aesthetic defect that will categorize the fruit as Class II (Zaid and de Wet, 2002a).

CHAPTER FOUR

4. THE AERIAL PLATFORM

4.1 Xiraffe

Xiraffe is a compact aerial platform, consisting of an articulated hydraulic boom lift mounted on a 4 wheel drive power unit, produced by a joint venture between ERREPPI, an Italian agro-transport tractors producer, and CO.ME.T., an Italian lifting machines manufacturer (fig. 4.1).

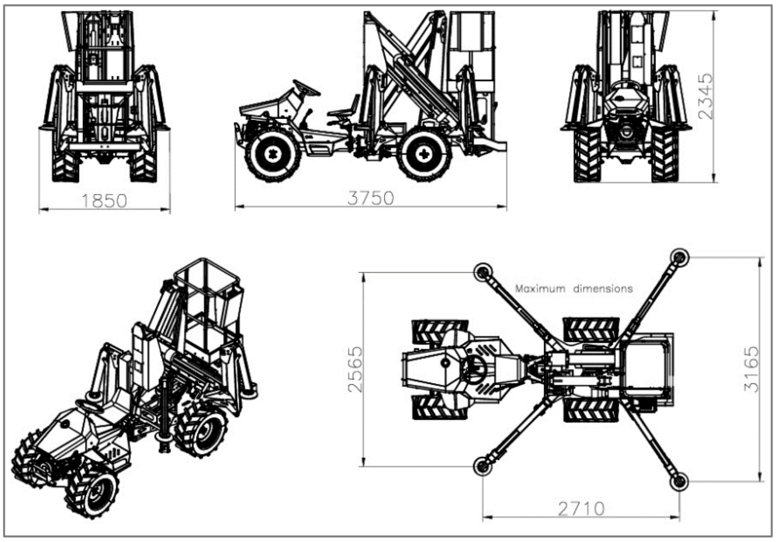

Figure 4.1. The Xiraffe with its platform components.

Founded in 1976, ERREPPI count an annual production of about 1000 units with 50% of production being exported into other EU countries. Nowadays, large part of the production is related to the oil palm sector by small and medium 4x4 agro-transport vehicles. These light and powerful machines ensure good performances with a low impact in the farm environment. This characteristic is particularly important in tropical area plantations, where the reduction of soil compaction is of primary importance in order to maintain good level of production along the years.

CO.ME.T. was founded in 1960 and has been one of the first companies to introduce in Europe the concept of "platform for aerial works", equipment that enables operators to work safely and with comfort at high altitude. The high rigidity of the structure, the accuracy of movements, the great resistance to heavy working cycles and the available safety devices allow these platform to be adapted to several sectors (construction, industrial etc.) being used in all the world. The recent partnership with XTRUX improved the know-how and experience resources inside the company.

It's from these bases and background that Xiraffe has been developed with the aim of offering a real and rentable solution for the improvement of mechanization status in date palm cultivation.

4.1.1 The platform

The aerial part is composed of a basket held by an articulated boom lift, supported by four hydraulic outriggers. The platform lifting system is hydraulic and is activated by an always running hydraulic pump, moved by the power unit engine through a transmission belt. A main valve controls the hydraulic circuit, allowing fluid flow towards the lifting system only when the outriggers are well opened and the pressure on each one of them is between 5 and 295 kPa; at the same time, this valve doesn't allow the fluid to activate the outriggers when the boom has been moved from the initial position, in order to maintain the previously achieved stability. This system can only be interrupted by special emergency levers. The outriggers have a supporting surface of 314 cm^2 each and are controlled by a micro-switch based system and a warning signal is emitted when one of them is losing pressure on the ground and stability could be affected. The outriggers are positioned manually by the operator and the machine's attitude is checked on the control panel and a bubble level; the outriggers can be adjusted to a maximum difference in height of 0.78 m at a distance of 2.565 m, allowing the placing of the machine even on a very uneven terrain. The maximum distance between the outriggers is 3.165 m (fig. 4.1). The aerial system can be guided by two fully hydraulic controls, one in the basket, placed externally, and the other at the base of the unit. The basket has a rectangular base of 1 m x 0.7 m and a height of 1.1 m with a rated maximum loading capacity of 150 kg, though no specific sensor controls this limit. It will be therefore responsibility of the operator not to load more than necessary. But some support come from the machine anyway. In fact by a sound signal the four outriggers will warn if they are losing pressure on the ground and loss of stability with risk of overturning may occur; furthermore, if the platform is subject to an excessive force further extension of the boom is disabled. The basket can be raised in 40 s at its maximum height of 9.8 m (basket floor) that means an average reach of 11.8 m, considering operator's height; the maximum outreach is 4.5 m from the boom's pivot vertical axis, that can be accomplished at a height of 7 m (fig. 4.2). The turret rotation range is 360° which makes it possible to access all the surrounding area. If safety limitations are respected the platform is rated for working up to a maximum wind speed of 15 m/s. The basket is provided with a 230 V electric outlet and a compressed air outlet for connecting different tools such as secateurs, chainsaw, sprayers etc. At the moment either electricity or compressed air have to be provided by an external source. External canisters can be also hung on the basket's railing to collect the harvested dates (fig.4.3).

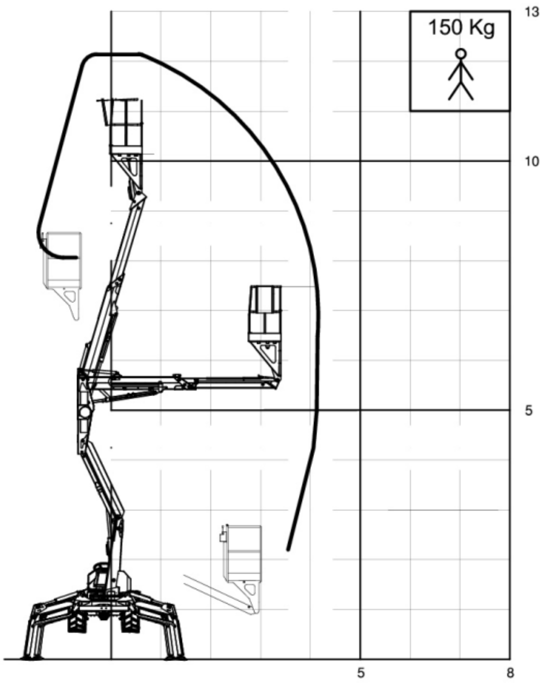

Figure 4.2 and 4.3. Platform aerial movements (left) and Xiraffe during field operations (right).

4.1.2 The vehicle

The power unit is a compact all-terrain tractor powered by a Yanmar L100N single cylinder, 435 cc air cooled Diesel engine, with a maximum power output of 8.3 kW. The engine is equipped with electric start and a 12 V battery with a capacity of 50 Ah. The unit is 3.75 m long and 1.85 m wide (Figure 4.1) with a front and rear wheel track of 1 m and 1.17 m respectively and a wheelbase of 1.975 m; the steering angle reaches 27.5° for each side; the ground clearance is 0.27 m and the total weight is 1,680 kg including the platform.

A synchromesh five gear plus reverse transmission allows Xiraffe to have a wide range of speeds from 1 km/h to a maximum of 18.9 km/h, while the average fuel consumption is about 0.6 kg/h at an engine speed of 3,000 rpm. Disk brakes are mounted on each wheel. Transmission is part-time type, allowing to select traction of 2 or 4 wheels depending on the situation. This guarantees good mobility in all the types of roads making possible also long transfer inside or outside the plantation.

Being the platform load mainly concentrated on the back wheels, the total maximum weight per wheel reaches 565 kg, so low pressure flotation tires (82 kPa) have been adopted in order to allow moving also on soft or sandy soils without damaging the irrigation systems or the grove environment. The vehicle is also provided with a rear hitch for towing a 500 kg trailer.

These characteristics make the unit very versatile and well suited for operating also in tight and rugged environments (fig 4.4 and 4.5).

Figure 4.4 and 4.5. In the picture, Xiraffe vehicle after placing and ready for lifting operations.

CHAPTER FIVE

5. METHODOLOGY

5.1 Evaluation method

The evaluation was conducted by comparing manual and mechanically assisted harvesting in terms of time, productivity and out-of-pocket costs (fuel).

5.1.1 Farms characteristics

The tests were carried out in three different farms, all located within 1 km along the Middle Jordan Valley. In all farms, the main product was represented by Medjool dates with some secondary production such as Barhi dates, citrus and grapes. All farms were characterized by medium texture sandy/loamy, deep soils. All the cultivation practices carried out at the frond level, from pruning to harvesting, were still done manually, in the traditional way, while some mechanized equipment was used for the post-harvest processes. Tending of the palms was mainly managed by Egyptian workers, which are employed for the harvesting season or all year round. In fact, the number of workers doubles during the harvest period. The age of workers was between 18 to 44 years old.

In general, as first harvest of the season, a huge amount of dates was expected to be collected. However, since the plantations were quite young, most of the palms in the farms were less than 15 years old. For this reason it has not always been possible to find sufficiently tall palms (higher than 6 m) and the selection of the tallest ones was important in order to make trials significative. The three farms were:

– *Al-Sughaiyer Co*. plantation, a 5.2 ha farm leased with a 5-year contract; the grove was constituted by 717 palms (700 Medjool and 17 Barhi) with an 8 x 8 m plant spacing. Pruning is done every second year, with a consequent presence of a high amount of leaves. Only in one sector, where older palms were available, it has been possible to find palms high enough to perform the tests (fig. 5.1 and 5.2) (table A.1, appendix A).

Figure 5.1 and 5.2. Al-Sughaiyer Co. plantation and plant pictures.

–*Jeneidi* farm, a family-run grove of 3.7 ha with 470 palms (455 Medjool and 15 Barhi) with a 9 x 9 m plant spacing. Secondary production is based on grapes and a nursery of ornamental palms is also part of the business. In this farm it has not been possible to find plants higher than 5.4 m because of the young age of the plantation, that was less than 12 years old. In general the plants were very well kept making interesting to do some trials even in this environment (fig. 5.3 and 5.4) (table A.2, appendix A).

Figure 5.3 and 5.4. Jeneidi plantation and plant pictures.

–*Arar* farm owned by an entrepreneur with a 30 ha total area and 2,700 Medjool palms with an 8 x 8 m pattern. Other cultivations are Barhi (1,100 palms), citrus and grapes. In this farm there was a wide variety of palm sizes and shapes which allowed to carry out trials in many different situations. In this farm the most important tests were done and where was possible to have a real comparison within mechanical assisted harvesting and the manual one (fig. 5.5 and 5.6) (table A.3, A.4 and A.5, appendix A).

 

Figure 5.5 and 5.6. Arar plantation and plant pictures.

During the year, although with some differences, cultural operations are carried out according to this schedule:

In November they start with cluster removal and old leaves pruning. Then from December they commence with organic fertilizer distribution and land preparation. But it's in March that they furnish high amount of fertilizer, especially the ones rich in phosphorus (P). April is the pollination period, which is done traditionally, by placing manually two to three male flower strands between the female inflorescence. In general, the ratio is of 1 male each 50 palms. Then in May there is the fruit thinning. In most of the cases 40-45 spikelet with 10 fruits each are left on the bunch. Sometimes the complete removal of the cluster is executed. The coverage will follow and at the end is the time for harvesting. This begins in August for Barhi, which is an early ripening variety, while the harvest of Medjool is completed in several times (in order to collect only the ripen dates) from the beginning of September to the end of October. Throughout the year, water is mostly supplied by drip irrigation. A higher amount is provided from November to August with a reduction during the last ripening stages to increase the quality of dates and facilitate the harvest and post-harvest processes.

5.2 Mechanically assisted harvesting

The aim of Xiraffe is to provide a complete support during the date palm cultural practices, as the harvest, facilitating the access to the frond level improving the efficiency and safety for workers. Therefore, it is still the operator that performs all the operations with the help of a safe and stable mechanical device instead than belt or ladders. At the same time, it will be also possible to use additional and pneumatics tools to reduce the fatigue of the operations and improve the general quality of the work. However, in our trial session, the attention has been focused on the harvesting operation.

Using Xiraffe for assisted harvesting, the first operation to be done, once the machine has reached the palm, is the positioning of the four outriggers; after this, the platform can be lifted by the operator itself or by a ground assistant. Once reached the cluster, the dates are collected and placed in plastic boxes and subsequently stored inside the canister. As common in Medjool plantations, only the ripe fruits are harvested and not the whole bunch: this is done by covering the bunch with a net bag and lightly shaking it, collecting only the dates that fall. Then, when the canister is full or all of the planned bunches have been harvested, the platform is lowered and the boxes manually passed by the operator on the basket to the one on the ground, which makes a first check and selection of the harvested dates. Once completed the task, the operator gets off from the basket, the outriggers are lifted and the machine is moved to the next position. During the trials, at the end of each day, the fuel tank was filled up to monitor the daily fuel consumption.

Servicing date palms with a platform can be done in two different ways: the first is harvesting with the "360°" method, that means servicing a whole palm with just one positioning of the machine which is done near to the palm base (Figure 5.7). By this, the operator has to be very careful to position the machine at the right distance from the plant and be able to surround all the frond by the correct platform movements.

Figure 5.7 and 5.8. Placing for the two different methods: "360°" (left) and "180°+180°" (right).

The second one is called “180°+180°” method that means servicing two half palms at a time and is done by placing the machine between two palms, in the middle of the row, and reaching only the half frond of each plant facing the machine (Figure 5.8). This was possible only in those plantations where the plants spacing did not exceed 8 x 8 m. This because with greater distances the maximum outreach from the boom’s pivot vertical axis doesn’t allow to reach all the desired bunches.

5.3 Manual harvesting

The traditional manual harvesting was done by skilled operators climbing up the palms with or without the use of a belt, sometimes with the help of a ladder, and by placing the collected fruits in a small bucket, with a capacity of about 5 kg of Medjool dates, and lowering it to the ground with the use of a rope (fig. 5.9 and 5.10).

Figure 5.9 and 5.10. Operator while climbing the palm (left) and placing collected fruit in the bucket (right).

5.4 Data collection

The monitoring and measurement of the different operations and environment characteristics was possible through the use of specific tools. In fact, were many the parameters to take in account for the evaluation.

The positioning of each harvested tree was detected by the use of the I-Phone 6 inbuilt GPS and the “GPS & UTM” application for I-Phone.

The distances from the trunk and the height of the dates bunches from the ground were measured with a Stanley TLM 99 laser telemeter, while the trunk circumferences with the use of a tape measure. In case of tilt plants, the inclination was evaluated by a projection of the frond core to the ground and then measuring the horizontal distance of this projection from the base of the stem. The weight of harvested dates was measured by a farm’s field spring scale, provided with a tray with a maximum capacity of about 3 kg of Medjool dates. These measurements were randomly verified in the warehouse by the use of a lager, 10 kg capacity, spring scale which evidenced an approximation of 10% in the field weighting system.

The daily volume of Diesel fuel consumption was quantified with a 2 l graduated container with a 0.25 l accuracy.

The time for carrying out the different operations in the manual and mechanically assisted harvesting was measured by the use of a chronometer. However, the harvest sessions were based on the repetition of the same procedures and it was through the comparison of these that was possible to check and evaluate the different service. For this reason it was useful to divide the whole process in different intervals:

– *Transfer*: in mechanically assisted harvesting the time needed to move the machine from palm to palm, from when the operator sits on the driver's seat to when he first touches the controls for the positioning of the outriggers. In manual harvesting, transfer is the time used for moving the equipment from one palm to the other. This was not always possible to measure so, after the first measurements, an average value of 30 s was considered for all the methods. In fact, especially with Xiraffe, looking for suitable palms that were not always next to each other, the machine moved within the plantations increasing the total time of this operation.

– *Placing*: the period from the end of transfer to the moment the operator is in the basket and ready for lifting. The main part of this operation consist in the positioning of the outriggers. This is very important since a good placement is fundamental to ensure a safe and stable work of the aerial platform. The operator carried out this task with great attention, checking continuously the electronic panel and bubble level. In this time also a 40 s period for loading the empty boxes into the basket is considered.

  In manual harvesting, placement is the preparation phase before climbing, during which the operator checks the palm and connects the rope to his arms or trousers' buckle. After the first measurements, it has been estimated in 30 s for the manual method.

– *Lifting*: from the first touching of the aerial platform control panel to the reaching of the date clusters. Within this, the first platform aerial movements are done.

  In manual harvesting, it is the period between the first touching of the ladder or of the plant to the touching of the clusters.

–*Harvesting*: the whole time used for harvesting, from the first touching of the cluster to the closing of the last cluster net bag. This is the same in both manual and mechanical one.

–*Descending:* from the completion of the harvesting to the positioning of the basket at the initial resting position.
In manual harvesting is the time from the end of harvesting to the touching of the soil by the operator.

–*Unloading*: the time needed by the operator on the basket to hand over the boxes to the ground operator. In a few cases, because of the high amount of dates harvested, lifting, harvesting and descending operations had to be repeated twice.

–*Disengaging*: from when the operator steps out of the basket to when he sits again on the driver's seat after lifting the outriggers, ready for the transfer to the next palm.

The number of leaves of each palm was counted in order to assess the frond density. This was a very important indicator since a high amount of leaves may represent an obstacle to reach the clusters in different positions and heights. Because of this, three main density classes were defined:

- *120 leaves*: High density of the frond. The clusters are completely covered by the frond and it's hard to reach them (fig. 5.11).
- *100 leaves*: Medium density of the frond. The clusters are still inside the frond but it is much easier to reach them (fig. 5.12).
- *90 leaves*: Low density of the frond. Few clusters are completely out from the frond and all of them are easily reachable (fig. 5.13).



Figure 5.11, 5.12 and 5.13. Frond density 120 leaves (left), 100 leaves (center) and 90 leaves (right).

5.4.1 Training

As common in mechanization, when new equipment has to be used operators must be trained to learn how to manage and operate the machine properly and safely. In this case, due to lack of workers, only one operator from Jabaly Agricultural Co., a local Company which gave an important sustain to this study, could be trained and therefore was in charge of operating the machine during all trials. In this situation a 4-hour course, given by expert technicians of the manufacturing Companies, was enough to demonstrate and analyze all the different functionalities of Xiraffe, allowing the operator to experiment the different situations that may occur when using this kind of machine. In the first two hours the trainers explained in deep all the functionalities of the machine, remarking the security conditions that must be followed. These regards a correct arrangement of the outriggers and a safe use of the platform at different heights and with different weights. In fact, since there were not specific devices to advice about the total weight on the platform, the operator had to be always aware of not exceeding the maximum loading capacity of 150 kg. At the same time he had to know about the possibility of contacts between the hydraulic boom and other part of the machine when the platform is working at low heights.
In the last two hours the trainee was able to start working autonomously with the constant supervision of the expert technician in all the phases.

After this, the operator practiced for 3 days in order to acquire the necessary experience and skills. This was important to avoid any loss of time or unexpected events during data collection period. During these days, various tests about the different servicing methods on palms with disparate characteristics in shape and height were carried out. Additional tools, such as the pneumatic chainsaw, for the pruning of old leaves have also been used. This was useful to underline the versatility of Xiraffe and the possibility of providing an effective support in many other types of cultural practices and harvesting methods.
The trainings were done in *Abuayyash* farm, a large plantation located in the same area, where we were allowed to do just workout sessions and not the next harvesting trials.

During field trials, the operator was supported by a worker from the hosting farms. As a matter of fact, two workers are needed for the most efficient use of the platform: one in the basket for harvesting and one on the ground for assistance. Normally only the operator in the basket drives the machine and therefore needs specialized skills but, during the trials, the farm owners insisted to have their man harvesting the dates so the trained operator had to drive the machine from the ground panel, leaving to the other worker the task of harvesting and managing the dates. This system poses some hazard and should not be normally adopted, being even forbidden in many Countries.

To respect the maximum loading capacity, is also important to know the weight of the operator in the basket, which was about 65 kg for all the workers that cooperated in the tests.

5.4.2 Trials

In order to have a complete dataset and to adapt our methods to the disparate farms' conditions different techniques were used for each environment along the trials:

In the Al-Sughaiyer Co. plantation, the selected palms were 15 years old and a total of 3 trials were done in the same day. Two times using the "360°" method and one time the "180°+180°". In general, the low maintenance at frond level and the consequent high amount of leaves didn't facilitate the reaching of all the bunches by the aerial platform. This was also the first day of real tests after the trainings, so the team was still working to have a good confidence performing the various operations.

In the Jeneidi farm, 5 palms were harvested with the use of the Xiraffe; only the "360°" method was adopted, but the number of operators varied: the first three times employing only one skilled operator for all the activities, while the other two times two operators were engaged. The low amount of leaves allowed to complete the session even if the palms were very short. Here, since only high quality dates are harvested, just the ones already available in the net (without shaking the clusters) were collected. This caused a lower total yield than the other plantations.

In the Arar farm, a total of 15 trials were done, 5 per day. The large availability of palms of different ages and heights facilitated the realization of various tests and a complete data collection in mechanical assisted harvesting operation. In the first day the "180°+180°" method was used, while in the second and third days the "360°" technique was applied. During these days it was even possible to monitor and evaluate the manual harvest and to proceed to a real comparison within the different methods.

Changing servicing method and number of operators was a consequence of the novelty constituted by the kind of operation that needed to be gradually adjusted, since neither the Xiraffe nor the mechanically assisted harvest had been experimented before in these farms, and of the need to adapt to different situations that arise in the various locations.

CHAPTER SIX

6. RESULTS AND DISCUSSION

6.1 Environmental factors

6.1.1 Impact on the environment

The variability of the farms conditions concerning types of terrain and slopes didn't influence the capacity of Xiraffe to access the desired area. The machine was able to pass all the obstacles and to cross easily the irrigation furrows. The movements were agile along dirt roads inside the farms or on the paved ones within these. No damages to the PVC pipes for drip irrigation due to the passage of the machine have been noted. There were only minimal disturbances, due to the light soils and so very easy to repair, on the small irrigation channel surrounding the palms, because of the passage of the wheels or by the outriggers positioning above these. This confirmed the low environmental impact of the machine and the high maneuverability and sustainability of light mechanization in date palm plantations.

6.1.2. Access to the frond level

The aerial platform proved to be easily handled through the fully hydraulic controls in the basket and at the ground level. The facility of movements made it possible to reach quickly any point in the surrounding area. But few limitations may be identified in the access to the frond level since the movements of the platform have to face several obstacles. In particular, the easiness of access to the date clusters depends mainly on their position, being frond coverage and height from the ground the most important factors.

Figure 6.1 shows how the machine proved to be fully efficient in reaching clusters in a range between 4.4 and 9.4 m height with a normal frond density of about 100 leaves per plant. In these conditions, Xiraffe allows harvesting all the palm's bunches with only one positioning ("360°" method). However, when cluster height is lower than 6 m, the boom geometry makes the platform progressively more difficult to manage because of the projection of the lower sections and the possibility of contact with the outriggers or other parts of the machine (fig. 6.2 and 6.3). For this reason, the suggested height range is within 6 to 9.4 m height.

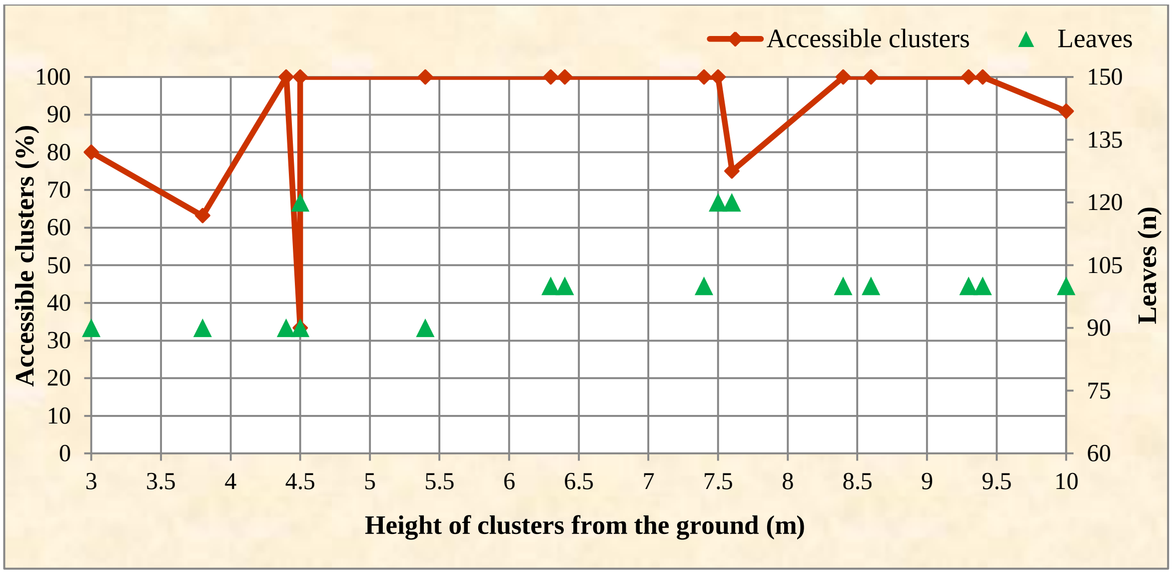

Figure 6.1. Main factors limiting access to the clusters in the 16 more significant trials.

The above mentioned limit in height of 9.4 is because of the possible movements of the platform at different heights (fig. 4.2). In fact, when height is above 9.4 m, the accessible area decreases, due to the aerial platform specific characteristics and geometry, not allowing a 360° access around of the stem.

Figure 6.2 and 6.3. Points of contact within the platform and other machine components.

Figure 6.1 also shows how high leaf density negatively affects the access to the bunches; this is because the volume of the basket, hinders its capacity to penetrate through the canopy and the operator has to open his way between the leaves or crouch down in the basket, hence losing the full control of the platform. This problem is worsened by the canister that increases the volume of the basket and consequently its capacity to move across the fronds. In two cases the palm leaves were seriously damaged because of the basket movements inside a high density frond. Then, they didn't attach well to the railings and when empty, the palm's leaves could make them detach and fall to the ground. So, in order to facilitate the movement inside the frond and avoid any damage to leaves, the operator used to place the canister on the basket's side free from palm leaves (the one opposite to the stem). Such procedure was very hard and risky, especially when the canister was partially full. This situation took to avoid the use of the canister where palms have a high number of leaves and to renounce the harvesting of all the bunches.

They are therefore height and frond density the most limiting factors within palm's features. If the palm's height may be quite hard and complex to regulate, much more could be done in the leaves and bunches management where progress in these operations may reduce the frond density and facilitate the access of the machine to the crown level.

Concerning the stem's size, the results were not influenced by different diameters which ranged from 0.42 to 0.62 m, though keeping the stem trimmed is still recommended.

6.2 Harvesting time

The 23 trials were done on plants of different characteristics regarding heights, amount of dates to be harvested, the number of leaves and stem diameters. Along these 23 harvesting sessions, the team has progressively improved the confidence and quality of performances of the different operations. For this reason, out of 23 trials, only 8, coming from the last two working days, were in the ideal conditions regarding palms height range and the team coordination in operating the Xiraffe. In figure 6.4 is possible to see the total harvesting time and the total amount of dates harvested during these 8 trials.

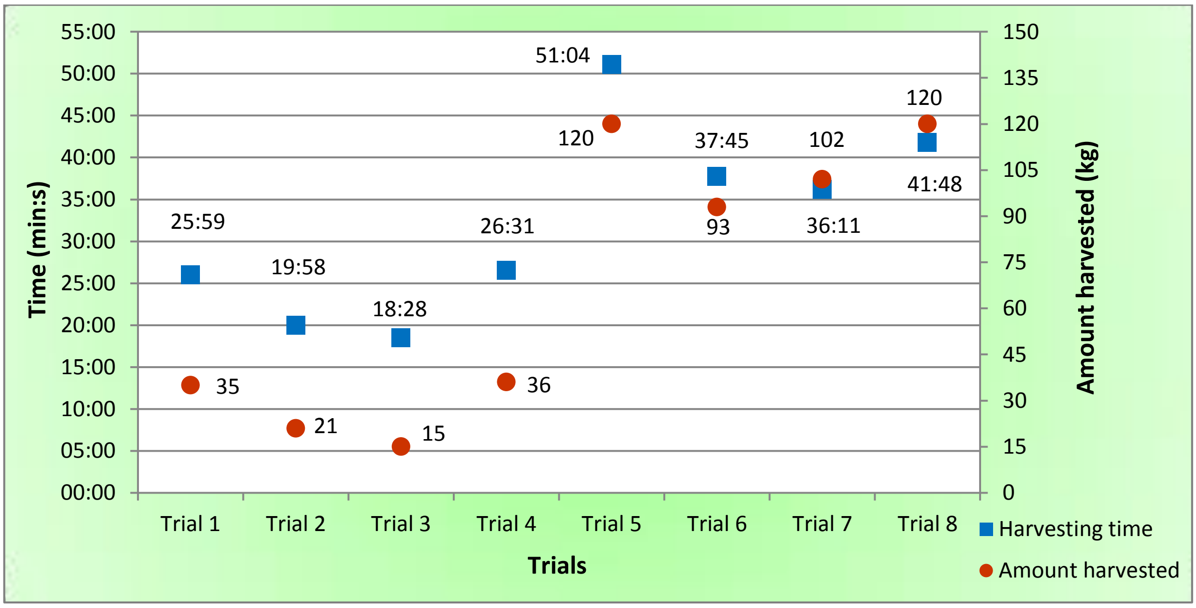

Figure 6.4. Harvesting time and quantity in 8 different trials.

The average time for harvesting one palm was of 1,933 s (32’13”) with two operators involved. However, harvesting time varied greatly from one palm to another being influenced by the amount of dates to be harvested and the different frond characteristics. This is particularly evident in the difference of total time between the first four trials, where the harvest was quite low, and the last ones, where it was much higher.

This is because when the total amount of dates per palm exceeds 60 kg, which is the maximum storage capacity of the basket and the canister together, an intermediate unloading is necessary, increasing the total time of the session (fig. 6.5). The intermediate unloading consists in the descent of the whole platform, the delivery of the harvested dates from the basket to the ground operator and then lifting operations to complete the harvest of the desired bunches. As a matter of fact, this extra operation nullifies the gain in productivity (quantity harvested/time), due to the high amount harvested in one single session, and builds up extra time losses (fig. 6.6).

Figure 6.5 and 6.6. Canister completely full of dates (left) and dates harvested with an intermediate unloading (right).

At the same time, the high frond density limits the movements of the platform and reduce the possibility of the basket to sneak within the leaves. This leads to waste of time due to the maneuvers that the operator has to do in order to reach the clusters. In these cases is not even possible to use the canister because an increase of volume at the basket level, will reduce the agility of the aerial platform inside the frond, limiting the number of clusters that can be achieved by the aerial platform.

Given that, during the 8 trials time increased with the amount harvested, a considerable difference can be noted between sessions where the total harvested amount was below or above 60 kg. In particular, sessions 5 was the slowest one because of the high amount of leaves on the palm that forced to remove the canister, hence reducing the storage capacity and making necessary two extra unloading operations. This shows that, apart from the previously mentioned usefulness of pruning the older and less productive leaves, the size and shape of the basket are very important and solutions should be thought of increasing its loading capacity.

In particular, the canisters didn't turn out to be a satisfying solution and should be redesigned. Unloading dates from the basket should be better organized as well since this was the slowest operation besides harvesting, taking 13.19% of the total time as shown in figure 6.7.

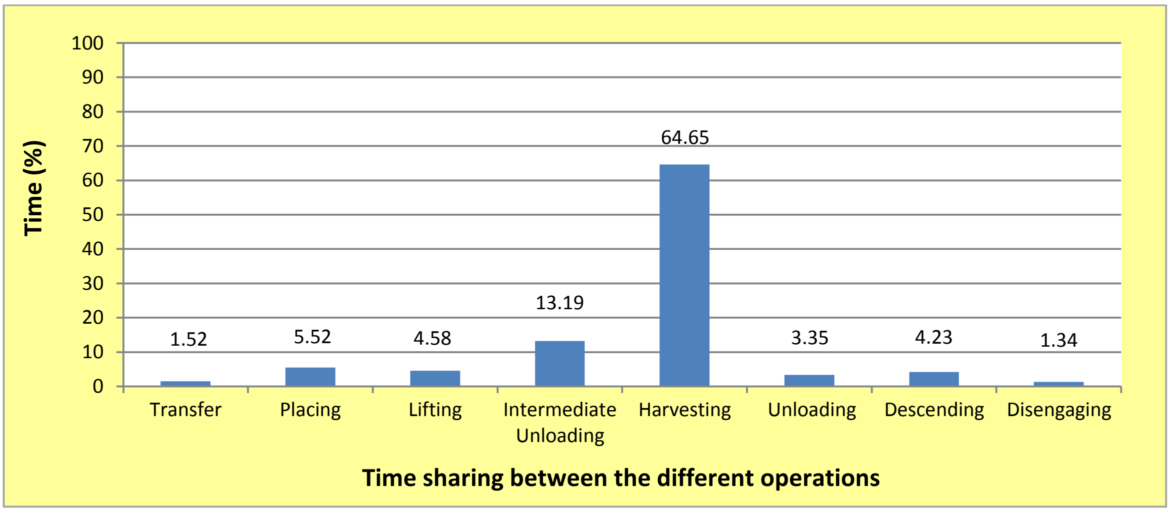

Figure 6.7. Time for single operation. Trials where one intermediate unloading was needed have been considered.

Among the other operations, lifting and descending were mainly related to the height of the palm and the ease of reaching the clusters or penetrating into the canopy. They were mainly between 1-2 minutes with extra time loss in those cases where the operator didn't maneuver the machine properly or some obstacle limited the aerial movements (table B.1, appendix B).

The placing was influenced by the terrain conditions. These were not always the same requiring a constant improvement of the operator's skills and ability, to adapt the outriggers' placement to the disparate situations that may occur. In all the cases, the placing was good and safe allowing to perform all the desired operations with a good level of stability.

Disengaging was simple and fast as the transfer, which was mainly influenced by the distance between the plants that were not always near to each other. Even if a standard value of 30 seconds has been considered for the calculation, in the cases where the plants were next to each other and absence of obstacles, time for transfer was about 25 seconds.

6.3 Harvesting productivity

An additional test concerned also the placing technique were the “360°” and the “180°+180°” were compared. The “180°+180°” method, however, was viable only in groves where the layout didn’t exceed 8 x 8 m and even in this case it was necessary to place the machine exactly at the same distance from the two palms, to be able to properly accomplish the task. But as common, the plantations were not always perfect so other situations, as plant inclined or irregular plant disposition, out from operator control, may happen.

The results show that, in terms of productivity, the “360°” technique proved to be the most effective for the harvesting within the optimum height range. Figure 6.8 shows the hourly average productivity with the two placing methods and with manual harvesting.

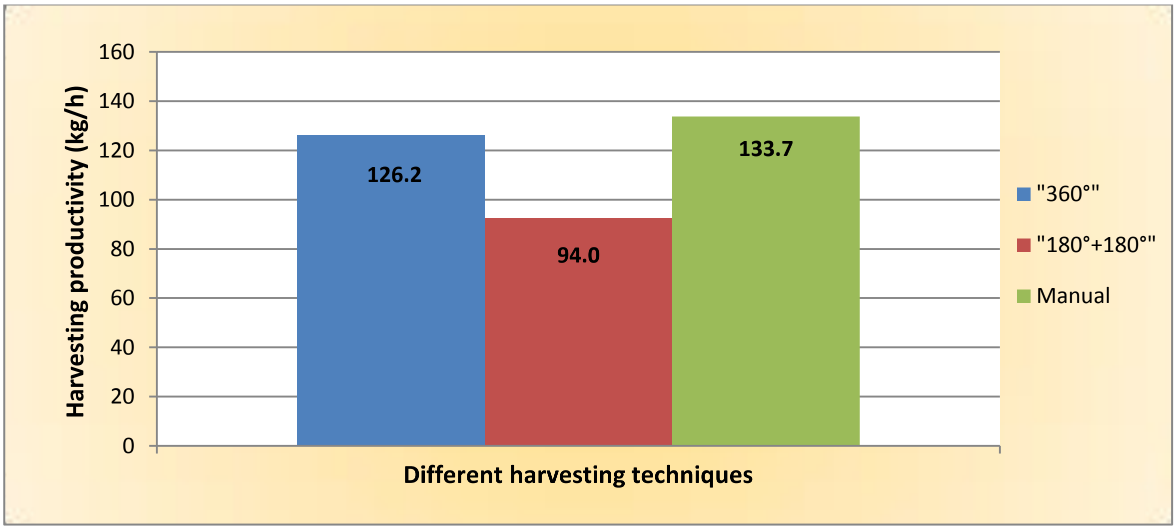

Figure 6.8. Harvesting productivity for each technique analyzed.

Moreover, in the “180°+180°” placing the distance from the plant affects the attainable height, as shown in the graph of figure 4.2, there is some time loss for the aerial moving from one palm to the other and the bordering plants of the plots need two placings anyway (table B.2, appendix B). The horizontally extended position of the boom also affects the stability of the machine when the load is high and in one case, one of the outriggers sent a loss of pressure alarm.

All this witness the importance of a good placing of the machine; the best distance from the rear wheel of the vehicle and the plant is in the range of 1.5-2 m since if the machine is too close or too far from the plant it is difficult or even impossible to carry out a complete 360° harvesting. In two cases, these distances were not respected forcing the operator to do a double placement with consequent losses of time. If palms are inclined, placement is easier and a single one under the frond is always enough for reaching all the clusters.

The results also show that manual harvesting is faster than using Xiraffe (fig. 6.8) (table C.1, appendix C). More detail is provided in figure 6.9 where the time needed for each single operation with manual harvesting and with the use of Xiraffe is reported. It can be seen that the machine is slower in the placing, descending and disengaging phases (also because some of these are not needed for the manual method), but it is faster in the harvesting and unloading operations even if the tests were in a manual harvesting friendly environment because of the high density of the fronds and the general low height of the plants.

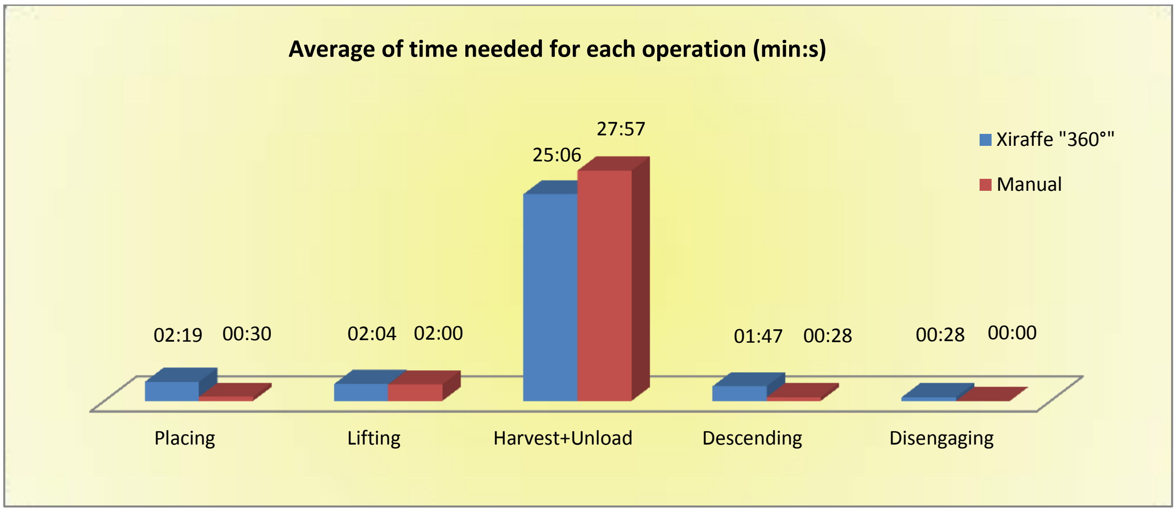

Figure 6.9. Time required for single operation with manual harvesting and with the use of "360°" method.

Of course, time for harvesting largely depends on the amount to be collected and Xiraffe proved to be more efficient where a huge amount of dates had to be harvested.

The collected data also show that productivity ratio between mechanically assisted and manual harvesting increases with palm height and harvested amount: when palms were above 7 m and more than 60 kg of dates had to be harvested, the continuous lowering and hoisting of the climber's small bucket can take a long time and be quite tiring, making up for the extra time required for the intermediate unloading operation of the mechanically assisted harvesting. In table 6.1 manual and mechanically assisted harvesting productivity is compared to different collected quantities when palms were above 7 meters high.

Method	Manual		Xiraffe “360°”	
Height(m)	8	7.6	8.4	7.5
Quantity (kg)	35	90	36	96
Time (h:mm:ss)	0:20:30	1:01:37	0:26:31	0:40:24
Total (kg/min)	**1.71**	**1.48**	**1.36**	**2.38**

Table 6.1. Effectiveness of different harvesting methods where palm height and harvested quantity are considered.

6.4 Further details about the operations

During the trials, the farmers proved to be very open and disposal to let us to do our work on the plants we chose. However, they asked for the specific machine assistance twice, in order to be able to harvest safely palms that were dangerous to climb because of rotten parts in the stem or leaves. The palms were easily harvested avoiding any kind of risk for the operator. In these cases, Xiraffe was a suitable alternative for performing this and any other operation at the fronds level proving to be a decisive support in the various situations that may occur within a plantation.

The only problem in machine functioning was an unintentional inclination of the basket, induced by an air bubble in the hydraulic system. The basket could be realigned only from the ground panel, which was not always easy to manage because during the platform rotation some other machine components may cover it. This problem was promptly solved following manufacturer specific instructions suitable for this case. Doing specific movements the air bubble was expelled avoiding other disturbances. An additional small complication was related to the anti-slide floor of the basket. It was really hard to clean it from the fallen dates consequently trampled by the operator, becoming immediately dirty and attracting many insects. In general, the losses of dates were very low, as well as those of manual harvesting, in a range from 0 to 3 % of the total harvest.

In order to evaluate other functions and potentialities, the use of pneumatics tools was tested apart from harvesting trials. A small chainsaw and secateurs were connected to the compressed air outlet in the basket and used for pruning the leaves or for cutting the whole clusters when needed. Even if the operator did all the necessary operations using the tools, he has been forced to keep them on the basket floor during the aerial movements, evidencing a lack of safeness and a loss of time as well. However, this was to verify that Xiraffe doesn’t work just as an operator lifting machine but that has multifunctioning characteristics extending its usefulness to many others cultural operations (fig. 6.10).

Two workers were needed for a correct and easy development of the operations. However, the second worker, the one attending to the platform on the ground, was not fully involved in the operations becoming necessary only for the unloading and could be employed for other activities while idle (i.e. cleaning and arranging of harvested dates, attending other workings, etc.).

The total fuel consumption was in the range of 0.75 l/h, which was an additional indicator of Xiraffe low impact and environmental sustainability.

Figure 6.10. Utilization of additional pneumatic tools.

CHAPTER SEVEN

7. CONCLUSIONS AND RECOMMANDATION

7.1 CONCLUSIONS

The performances recorded during the trials show that Xiraffe is able to reach and easily work in areas where access for larger machines would not be possible, without upsetting the grove structure and environment, and to allow an operator to reach up to the frond level of medium height to moderately tall palms, in a safe and effective way.

The best way of using Xiraffe is through the "360°" method, which guarantees the best results and adaptability to various farms' and palms' conditions. In fact, even if the tests were done in an environment not properly arranged for mechanization, the machine was able to overcome most of the obstacles.

These characteristics can lead to interesting results and implications since this machine can fill the gap between expensive heavy and high productivity equipment and basic, ineffective and sometimes dangerous manual operations. The capacity of better performing, where palms are taller and bear high yield, makes it a possible option for established and well-tended medium sized farms, where the value of the product allows for investing in mechanization, possibly by pooling, or for contractors, which can better exploit this kind of equipment. This is particularly true when the labor force is scarce or expensive.

On the other hand, this machine is susceptible to improvements, many of which have been glimpsed in this first study, in order to reduce timing of operations and productivity; this is also because the platform component of Xiraffe is at the present derived almost completely from another area, that is the construction sector.

In conclusion it is possible to foresee the opening a new scenario in commercial date palm cultivation, though further tests should be carried out, after reviewing some of its' characteristics, possibly on larger scale, where also the effect of fatigue of operators could be considered, either with manual or mechanically assisted harvesting, and, in case of using the platform, also of their gain in experience in placing and operating the machine.

7.2 RECOMMANDATIONS

In order to increase Xiraffe performances and productivity, some improvements of the machine and of the plantation environment may be developed.

As normal when mechanization is introduced in agriculture, also the crop should be adapted to the machines, making their action easier, so some modification can be studied also for the plantations, especially for the new ones, taking in consideration that when they will be productive, probably importance of mechanizing will be more evident. At the present, the most evident need for improvement that has emerged is the pruning of the leaves and possibly arranging of the bunches, which make much easier the access to the clusters.

About the machine, some of the most important modifications would concern:

- Basket capacity. The current basket has a low volume which facilitate the cross and possibilities of movements within high density fronds. However, the addition of lateral extensions, to open in case of need, could facilitate the full harvest of the palm at several heights and reduce the number of maneuvers to reach the different bunches. This improvement will be very useful in palms well pruned, where the clusters are not completely covered by the frond.
- Basket shape. A circular basket will facilitate the sliding of the canister on the railings. This will help the operator to move easily the canister on the desired side reducing the impediment and damages that it can cause.
- Basket control panel position. An additional way to ameliorate the basket agility within the leaves is to place the control panel inside of it. This will reduce much more the total external volume increasing the ease of moving in front of different obstacles.
- Basket floor. The current anti-slide floor could be replaced by a grid one, to facilitate cleaning and reduce the insect attractiveness.
- The possibility of unloading the harvested dates without descending. This is one of the main aspect to develop since it will enhance machine productivity by reducing considerably the total execution times. It could be done by a basket release mechanism that can work while the aerial platform is still at height.

- Additional tools management and energetic sources. Adding some specific support on the basket would facilitate the management of tools along the aerial movements and all the different operations. Then, the possibility of having energy produced directly from the machine itself instead of using external sources, it could make easier their use and improve the independence of Xiraffe from other devices.
- Development of one specific side of Xiraffe to perform the operations. In fact, even if the versatility of movements in the platform surrounding area will be reduced, this will ensure better performances on a precise part of Xiraffe that will be the one always facing the selected palm. In this way, it will be possible even to study new solutions to improve the stability and the maximum loading weight of the platform (ballasting, etc.), developing the potentialities of working with the "360°" method.
- Safety devices to avoid the points of contact. The inclusion of specific sensors that stop the platform when it's going to impact with other machine components will support the operator to perform safely all the movements. This will also improve the suitability of Xiraffe working at low heights.
- Ground panel position. A new position should be found for this in order to avoid the possibility to be covered by other parts of the machine during the turret rotation. This can be done even by a joystick that will facilitate, in case of need, the follow up from the ground level.
- Automatic placement. A system that proceed to the outriggers disposition autonomously, will be useful to reduce the total time of each harvest session. In this case, the operator will just check the correct placing doing small changes only if needed.

Of course, it will not be possible to make all these changes since the realization of one could sometimes exclude the other. And the total cost is also something to take in account during the machines development. However, an increment in productivity and machine suitability, will enhance the levels of efficiency and safety for workers allowing a faster repayment of the investment thus facilitating any market prospects.

It is therefore recommended a joined development between environmental conditions and machine characteristics, with skilled and trained operators, to enhance the spread of this type of mechanization.

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APPENDIX A

Data of date palm measurements

Table A.1. Characteristics of the palms harvested in Al-Sughaiyer Co. plantation.

Al-Sughaiyer Co. – Palms' features				
Trial of the day	1	2		3
Method	360°	180°+180°		360°
Clusters height (m)	4.5	6.7	7.3	7.1
N° of clusters	21	6	7	15
Yield (kg)	40	30	35	40
Diameter (m)	0.48	0.5	0.51	0.46
Number of leaves	120	120	120	100
Habit	Right	Right	Right	Right

Table A.2. Characteristics of the palms harvested in Jeneidi plantation.

Jeneidi – Palms' features					
Trial of the day	1	2	3	4	5
Method	360°	360°	360°	360°	360°
Clusters height (m)	3.8	4.5	4.4	5.4	3
N° of clusters	19	18	17	21	15
Yield (kg)	4	10	11	18	5
Diameter (m)	0.62	0.62	0.61	0.58	0.6
Number of leaves	90	90	90	90	90
Habit	Right	Right	Right	Right	Right

Table A.3. Characteristics of the palms harvested in Arar plantation the first day.

Arar (day 1) – Palms' features										
Trial of the day	1		2		3		4		5	
Method	180°	180°	180°	180°	180°	180°	180°	180°	180°	180°
Clusters height (m)	7	7.4	7.7	8.3	8.1	8.2	8.2	7.4	8.4	8.4
N° of clusters	5	6	9	9	7	9	5	5	9	6
Total yield (kg)	25		35		16		42		15	
Diameter (m)	0.58	0.52	0.59	0.49	0.6	0.58	0.59	0.59	0.48	0.5
Number of leaves	100	100	100	100	100	100	100	100	100	100
Habit	Right	Right	Right	Right	Right	Right	Right	Tilt	Tilt	Tilt

The plant inclination of trial 4 was 0.9 m. The direction was opposite to the machine placement inside the row. For the other two palms, the inclination was respectively of 1.6 and 1.2 m but in the direction of the machine so with the frond inside the row.

Table A.4. Characteristics of the palms harvested in Arar plantation the second day.

Arar (day 2) – Palms' features					
Trial of the day	1	2	3	4	5
Method	360°	360°	360°	360°	360°
Clusters height (m)	9.4	9.3	10	7.4	8.4
N° of clusters	9	9	10	7	10
Yield (kg)	35	21	30	15	36
Diameter (m)	0.46	0.46	0.5	0.46	0.44
Number of leaves	100	100	100	100	100
Habit	Right	Tilt	Right	Right	Right

The inclination of the palm was equal to 0.45 m. However, since the "360°" method was used, the direction is not relevant because the machine will be directly placed under the frond.

Table A.5. Characteristics of the palms harvested in Arar plantation the third day.

Arar (day 3) – Palms' features					
Trial of the day	1	2	3	4	5
Method	360°	360°	360°	360°	360°
Clusters height (m)	7.6	7.5	6.3	6.4	8.6
N° of clusters	7	16	12	15	19
Yield (kg)	24	120	93	102	120
Diameter (m)	0.45	0.42	0.46	0.44	0.45
Number of leaves	120	120	100	100	100
Habit	Right	Right	Right	Right	Right

Table A.6. Characteristics of the palms harvested in Arar manually.

Arar (Manual harvest) – Palms' features									
Trial of the farm	1	2	3	4	5	6	7	8	9
Clusters height (m)	8	5.9	4.8	6.6	5.6	5.7	5.8	5.9	7.6
N° of clusters	9	18	19	18	19	10	11	16	19
Total yield (kg)	35	9	48	117	81	30	36	114	90
Diameter (m)	0.57	0.5	0.47	0.48	0.48	0.42	0.43	0.41	0.45
Number of leaves	100	100	100	120	120	100	100	100	120
Habit	Right	Right	Right	Right	Right	Right	Right	Right	Right

In most of the cases, dates palm harvested manually are much shorter than the one harvested with mechanical assistance. This because of the low amount of tall palms that were mainly harvested with Xiraffe.

APPENDIX B

Data of Xiraffe harvesting measurements

Table B.1. Times for harvesting by Xiraffe using "360°" method.

Times: Xiraffe "360°" method (mm:ss)								
Trials	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8
Transfer	00:30	00:30	00:30	00:30	00:30	00:30	00:30	00:30
Placing	01:10	01:50	01:15	02:35	02:25	01:40	01:07	01:12
Empty Boxes Uploading	00:40	00:40	00:40	00:40	00:40	00:40	00:40	00:40
Lifting	01:44	01:53	03:20	02:00	01:45	03:00	01:49	00:58
Intermediate Unloading	00:00	00:00	00:00	00:00	11:20	05:30	05:00	05:30
Harvesting	19:10	11:30	09:30	17:30	30:34	23:00	24:00	28:40
Final Unloading	01:00	01:00	01:00	01:00	01:00	01:30	01:30	01:30
Descending	01:20	02:20	01:55	01:44	02:20	01:30	01:25	01:42
Disengaging	00:25	00:15	00:18	00:32	00:30	00:25	00:30	00:46
Total Time (mm:ss)	25:59	19:58	18:28	26:31	51:04	37:45	36:11	41:48

Table B.2. Times for harvesting by Xiraffe using "180°+180°" method.

Times: Xiraffe "180°+180°" method (mm:ss)					
Trials	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Transfer	00:30	00:30	00:30	00:30	00:30
Placing	02:40	01:57	01:55	02:00	01:45
Empty boxes Uploading	00:40	00:40	00:40	00:40	00:40
Lifting	02:50	02:10	01:55	01:45	01:35
Extra Aerial Movement	01:30	04:30	04:30	04:30	09:00
Final Unloading	01:00	01:30	01:30	01:30	02:30
Harvesting	17:14	21:00	22:30	14:30	25:55
Final Unloading	00:45	00:45	00:45	00:45	00:45
Descending	01:30	01:40	02:05	01:35	01:20
Disengaging	00:50	00:47	00:41	00:40	00:30
Total time (mm:ss)	28:44	34:44	36:16	27:40	43:45

Extra aerial movements correspond to the time used to move the platform from one palm to the other. In some case this value is much higher because an intermediate unloading was done from one palm to the other. The palms harvested correspond to the Arar farm ones.

APPENDIX C

Data of manual harvesting measurements

Table C.1. Times for harvesting by traditional method.

Times: Manual method							
Trials	Trial 1	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9
Transfer	00:30	00:30	00:30	00:30	00:30	00:30	00:30
Placing	00:30	00:30	00:30	00:30	00:30	00:30	00:30
Lifting	01:02	01:10	01:01	01:40	02:30	02:20	04:45
Harvesting	17:53	34:40	27:00	11:30	19:00	35:30	55:20
Descending	00:35	00:18	00:21	00:43	00:25	00:30	00:32
Total time (h:mm:ss)	20:30	0:37:08	0:29:22	0:14:53	0:22:55	0:39:20	1:01:37

The number of trials correspond to the number of the palms' features (table A.6, appendix A).