



2.	PLANTATION ESTABLISHMENT AND MANAGEMENT.....	2
2.1.	INTRODUCTION	2
2.2.	SOILS AND FIELD PREPARATION	2
2.2.1.	<i>Soil requirements</i>	2
2.2.2.	<i>Soil sampling</i>	3
2.2.3.	<i>Soil preparation</i>	3
2.2.3.1.	Planting holes	4
2.2.3.2.	Plant spacing.....	4
2.2.3.3.	Planting season.....	5
2.3.	JATROPHA PLANT DEVELOPMENT	5
2.3.1.	<i>Jatropha development stages</i>	5
2.3.2.	<i>Root development</i>	6
2.3.3.	<i>Flowering & fruiting</i>	6
2.4.	PLANTING MATERIAL AND PLANTING METHODS	6
2.4.1.	<i>Genetic and phenotypical variation</i>	7
2.4.2.	<i>Seed selection</i>	7
2.4.3.	<i>Germination</i>	7
2.4.4.	<i>Direct Seeding</i>	8
2.4.5.	<i>Nursery planting</i>	8
2.4.6.	<i>Cuttings</i>	10
2.4.7.	<i>Micro-propagated clones</i>	10
2.5.	PLANTATION MANAGEMENT (AGRONOMY)	10
2.5.1.	<i>Weeding</i>	10
2.5.2.	<i>Nutrient Management</i>	10
2.5.2.1.	Nutrient Requirements.....	10
2.5.2.2.	Organic matter	12
2.5.2.3.	Fertilization.....	12
2.5.2.4.	Mycorrhiza.....	13
2.5.3.	<i>Pruning</i>	13
2.5.4.	<i>Irrigation</i>	14
2.5.5.	<i>Intercropping</i>	14
2.6.	JATROPHA HEDGES.....	15
2.7.	SEED YIELDS.....	16
2.8.	PEST AND DISEASES.....	18
2.8.1.	<i>Control Measures</i>	19
2.8.2.	<i>Preventive Measures</i>	19
2.9.	REFERENCES	20



2. Plantation Establishment and Management

Main author: Ywe Jan Franken with contributions of Flemming Nielsen

2.1. Introduction

This chapter discusses the aspects of establishing and managing a jatropha plantation on a small scale (0.5 to 5 ha.). It elaborates on soil sampling, field preparation and planting. There are many options for starting a plantation, from seeds to cuttings and different plant-spacing arrangements. The growth process of the jatropha plant is described here. Subsequently, plantation management is described. Issues of fertilization and weeding belong to this topic. Furthermore, this chapter highlights the dangers and hazards on a plantation, including pests and diseases. At the end, there is a discussion of the various dry seed yields of a plantation.

2.2. Soils and Field Preparation

2.2.1. Soil requirements

Jatropha prefers well-drained soils with an open well-aerated structure. The soil types mentioned in the text below refer to figure 2 with the USDA soil classification based on grain size.

Most suitable soils are loam, sandy clay loam and silt loam.

Heavy soils (clay, sandy clay, clay loam, silty clay loam, and silt) are only suitable under relatively dry conditions when frequent periods of heavy rainfall are absent. In that case jatropha can be quite productive because these soils usually have a good nutrient supply. Jatropha cannot tolerate permanent wetness (it becomes waterlogged). Heavy soils, therefore, are only suitable when they are not saturated with moisture for long periods (maximum one week, which will already have a negative impact on production). These conditions occur when there are no periods of high rainfall that lead to water logging and when the groundwater table is out of reach. Heavy soils are not suitable under conditions where very dry and wet periods quickly follow each other because they shrink and swell and root formation is impaired.

Sandy soils (sand, loamy sand, and sandy loam) are soils that are prone to drying out quickly (unless they are very high in organic matter). On these soils jatropha has a comparative advantage over other crops, because it is drought tolerant. These soils usually are not high in nutrients, so jatropha will need fertilization or high organic matter application to the soil in order to be productive.

Regardless of the soil, a good pH for jatropha lies between 5.5 and 8.5. Under more acidic or alkaline conditions jatropha growth is limited. Soil depth should be at least 45 centimeters and soil slope should not exceed 30°. Jatropha can survive low soil nutrient contents, but in that case growth and production are limited. Higher nutrient levels in the soil translate into increased production. Soil organic matter is also favorable to jatropha growth, especially in coarse soils.



The figure below classifies soils according to sand, silt and clay content. The figure consists of three axes giving the sand content (left axis), silt content (right axis) and sand content (bottom axis). The various blocks in the figure indicate different soil types.

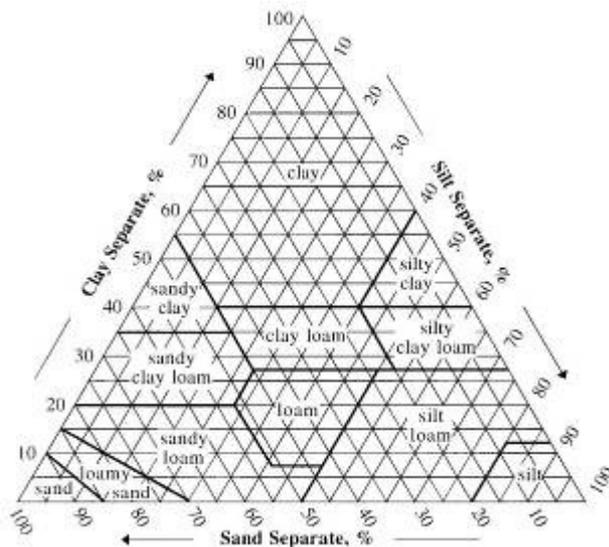


Figure 1 – USDA soil classification

2.2.2. Soil sampling

It is important to have a good indication of the soil type and fertility at the planting site. Before starting a plantation, soil samples should be taken and analyzed.

Soil samples should be taken at around 30 cm depth and per spot (100 m²) around 10 – 15 samples should be taken of 100 cm³ each. The location of each spot should be exactly described preferably by GPS coordinates. The samples should be pulverized and mixed well together to get 1 sample for analysis. One cup of soil should be put in a plastic bag, labelled and used for analysis. The remainder of the mixed sample should be labelled and stored as a backup. Per hectare, at least 5 mixed samples should be analyzed.

The clay, silt and sand content need to be measured to determine the soil type. Soil nutrient levels need to be measured for nitrogen, phosphorus, potassium and, preferably, also magnesium, zinc, copper, sulphur and calcium. Other aspects that should be included in the analysis are organic matter (OM), soil pH, cation exchange capacity (CEC) and saturation percentage of the CEC for potassium, magnesium and calcium.

The data should be professionally analyzed to get a good indication of soil fertility (low, medium, high) and the *Jatropha* production potential at the site (see also annex on seed yields). This can be done by a soil laboratory or by an external soil scientist. In case this is not possible a commercial soil testing kit can be used.

2.2.3. Soil preparation

The soil needs to be cleared from vegetation before planting, and weeds need to be removed.



2.2.3.1 Planting holes

When planting jatropha only, planting holes should be prepared. These holes can be dug with an axe or by drilling. On hard or compacted soils, ploughing or deep ripping of the soils is advisable, especially when considering intercropping, in which case the entire soil need to be prepared.

In case of hard-compacted soils, it is also possible to prepare lines for planting or seeding with a deep ripper which is a chisel plough with just one hook. A deep ripper should rip from 30-50 cm. deep. This will allow the root system of the jatropha seedlings to develop well. A ripper cannot be manually operated but must be used with animal traction or fixed to a tractor.

Holes for planting should ideally have the following minimum dimensions: diameter of 30 centimetres and minimal depth of 45 centimetres.

The holes should be refilled with a mixture of soil and organic matter (compost) in a ratio 1:1.

Artificial fertilizer or manure should be added. The amount of fertilizer added should be about 10- 20 grams of common N:P:K (nitrogen, phosphorus and potassium) fertilizer (from 6:6:6 to 15:15:15 or variations between these limits). The fertilizer should be mixed evenly. In case animal manure is used, about 0.5 kg would be sufficient per plant hole. The amount of organic matter can vary between 20% and 50%. The formula of the mixture then changes into soil: compost: manure in a ratio 2:1:1. In case of heavier (more clay) soils jatropha cultivation is not advised. However, in that case sand should be added to the mixture in a ratio of soil: sand: organic matter of 1:1:2.

The mixture should be free from stones and larger objects. Making the holes needs to be done just before the rainy season. Planting should start when the soils have received the first rains.

More fertilizer can damage the roots of the young seedlings and can best be added after one or two months. About 50 to 100 grams of the same NPK (see before) needs to be evenly distributed and mixed with the topsoil in a diameter of about 50 centimetres around the plant.

2.2.3.2. Plant spacing

Spacing in plantations can vary. A commonly applied plant spacing is in a rectangular pattern of 3 x 2,5 meters with 1333 plants/ha. When plants grow they need to have enough space for growth and branching. In this pattern there is enough space for intercropping in the first year and even the second year when jatropha develops slowly. Wider spacing leads to larger trees that grow taller and higher, which hinders harvesting and pruning. In a more narrow spacing - 2.5 m x 2.5 m or 2 m x 2 m - more intensive pruning is necessary to keep the plants from growing into each other. This requires a lot of extra labour. A more narrow spacing leads to a more intensive agriculture and requires soils with good nutrient and water supply.

In case of permanent intercropping, the plants should be planted in rows with a larger distance in between for other crops. The distance between the rows depends on the space needed for intercropping, usually about 4 meters. The distance between Jatropha plants within a row is 2.5 or 3 meters.

In case mechanized agriculture is considered, e.g. a tractor, there should be at least 4 m spacing in between the rows, assuming 2 meters for the tractor and 1 meter of branches on each side. The spacing between plants within a row can be reduced to 1.5 m in this case resulting in an overall spacing of 4 m x 1.5 m [31].



In living fences, plants should be spaced about 25 centimetres apart from each other in a single or in double rows. For quick establishment it is advisable to start from cuttings in the rainy season.

Monoculture jatropha itself is largely fire-resistant, but the burning of weeds and grasses will kill the plant. [31]. In fire hazard areas it is advised to split plantations into separate compartments by making fire lanes of at least 2 metres wide. This will prevent fire from damaging the entire plantation. These fire lanes should be kept free from weeds, crops and overgrown vegetation.

2.2.3.3. Planting season

The best time for planting is at the onset of the rainy season when the soil has taken up the first soil moisture. When water is available at low costs, it is possible to start planting several weeks up to a month before the rainy season.

After planting, extra watering of the plants is necessary only when the rains are not sufficient, and it can cease after 3 months of growth when the plants have developed their root system.

2.3. Jatropha plant development

To apply an optimal management of a jatropha plantation, it is important to understand the development stages of the jatropha plant.

2.3.1. Jatropha development stages

Starting from seed, jatropha goes through various stages of development.

The first is the juvenile stage. It starts with the seed that soaks up water when planted (imbibition) and is followed by germination. The small seedling then comes above the ground (emergence) and starts to develop shoots and roots (establishment). This juvenile stage takes about two and a half months under optimal conditions.

The second stage is the flower induction sensitive phase. At this stage the right environmental conditions (high radiation/ high average temperatures/ high minimum temperatures(>18°C) and sufficient rainfall can trigger flower induction. Flowering is the third stage. After pollination the fruit start filling and ripening, which is the fourth stage. The time from flower induction to harvest takes approximately 3 months. After harvest the plant may enter a stage of dormancy where it is insensitive to flowering or it may enter another flower induction sensitive phase. This depends on stress conditions, but the exact mechanism is not yet known.

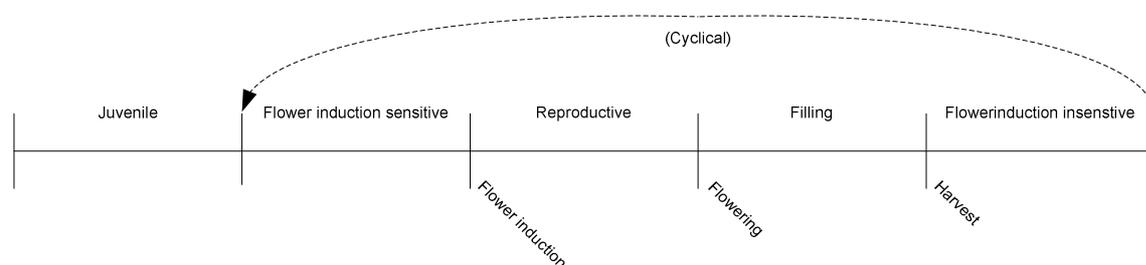


Figure 5 - Jatropha development stages [28]



2.1.1. Root development

After germination from seeds jatropha seedlings develop one taproot and four lateral roots. The root system thus grows both into the upper and deeper soil layers, provided the soil is deep enough. Figure 7 shows a jatropha root system where the left plant has developed a thick taproot growing down vertically.



Figure 7 – Jatropha root system.
Picture: Joachim Heller

In case cuttings are used, only lateral roots develop and no taproot.

2.3.3. Flowering and fruiting

Jatropha flowering is a complex matter. It is known that flowering is induced by stress factors, like temperature fluctuations and drought, but how exactly and at what thresholds this occurs is still unknown. For flower induction Jatropha plants need to be exposed to high solar radiation. Plants that grow shaded under trees or in clouded conditions do not flower or flower markedly less than plants in the full sun. In a climate with distinct seasons Jatropha starts flowering after these periods of stress have ended, which can be several times per year. In climates with an evenly distributed rainfall and no large seasonal variation in temperatures Jatropha may flower continuously when there are no other forms of induced stress.

Under optimal conditions, jatropha usually flowers about 3-6 months after the seeds have been sown. The time from flower induction to fruit maturation is 90 days. The female flowers produce fruits that are first green, and turn yellow when ripening. Later the yellow fruit hull turns brown and black when they dry.



Picture: The various stages of fruit development can be seen. The open fruits shows the black seeds inside. Source: FACT, 2006.

2.4. Planting Material and Planting Methods

One of the first actions to take when starting a Jatropha plantation is to obtain enough Jatropha plant material and decide how to produce Jatropha plants. Jatropha plants can be produced by seeds, cuttings, or by micro propagation. These methods and the suitability of these methods for different conditions are described below.



2.4.1. Genetic and phenotypical variation

Provenance trials and research into the genetics of *Jatropha curcas* L. has shown that there is some genetic variation between plants from different provenances (or accessions) that are growing worldwide. Natural genetic variation between provenances is largest in the centre of origin (Central America and the Northern parts of South America).

Plants grown from the same seed source can differ considerably in morphological aspects like plant height and seed production. It is not yet known to what extent this morphological variation can be attributed to genetic or environmental factors. When seeds from a certain location are collected, variation can be minimized by selecting seeds (see next part on seed selection).

2.4.2. Seed selection

First of all, it is important to obtain high quality seed material. When ordering seeds one should make sure they match the following criteria:

- Seeds come from high-yielding provenances that grow under similar agro-ecological conditions as where the plantation is planned.
- Seeds are a selection of the heaviest and largest seeds from these selected provenances.
- Seeds have a moisture content of around 7%.
- Seeds are young (preferably not older than 6 months).
- Seeds have been stored under cool, dark and dry conditions.

For information on clonal and seed gardens please read the Appendix: Clonal and Seed gardens Manual.

2.4.3. Germination

Jatropha seeds germinate easily when planted in soil at about 2 cm depth and with the white tip of the seed facing slightly downwards and the rounded side of the seed facing upwards.

Jatropha germinates in any soil with a continuously high humidity and sufficient air supply (in waterlogged soils *jatropha* seeds will rot). Pre-treatment of seeds did not show better results in germination compared to dry seeds directly planted in Mozambique [20]. Seeds with the above-mentioned characteristics will germinate within 7-8 days under hot (average temperature > 25°C) and humid conditions. Under cooler conditions germination takes longer. Seeds that germinate within 10 days are more vigorous and should be used.

Jatropha can be directly seeded in the fields or can be germinated in a nursery, depending on the factors that will be discussed hereunder.



Figure 6 - *Jatropha* seed germinating (left) and small seedlings that have just emerged (right). photo: Peter Moers

2.4.4. Direct seeding

The advantages of direct seeding are the optimal root development of the *jatropha* plants and lower costs for labour and materials as compared to setting up a nursery. A disadvantage is that the content of toxins in seedlings is low in the first months and rabbits and other animals can eat the emerging plants. Direct seeding is recommended in case sufficient water supply during germination and development of the seedlings can be guaranteed, e.g. when soils have taken up enough moisture naturally or by irrigation. When direct seeding, competition from weeds in the first 3 months must be avoided.

For optimal *jatropha* establishment, the seedlings should have access to easy penetrable, nutrient rich and organic matter rich soil to a depth of at least 45 cm. In case of compacted soils, planting holes should be made of about 45 cm deep and about 30 cm wide and should be filled with loose soil mixed with organic matter and preferably a basic mix of fertilizer/ manure.

Seeds should be planted as described under germination in the planting spots in the chosen planting pattern (common is 2.5 m x 3 m (see earlier part on 'plant spacing'). One should plant two seeds instead of one for every third planting spot at about 25 cm apart (so the root system of the two seedlings does not grow into each other). This will result in some spare seedlings that can be easily transferred. In case seeds in some planting holes do not germinate or are lost, the extra seedlings can be planted there. The extra plants can also be used to replace plants that develop slowly compared to the other plants or show abnormal growth (e.g. strangely shaped leaves). This selection step is important because slowly developing plants will produce less fruits and seeds and will have lower average yields.

The amount of seeds needed depends on the planting density. At a spacing of 2.5 m x 3 m, 1333 plants are needed, which requires 2000 seeds (including the extra plants for non-germinating seeds and to compensate for lost plants or replacement of low quality seedlings). This equals around 1.2 kg seeds/ha with an average seed weight of 0.6 grams.

2.4.5. Nursery planting

The advantages of growing *jatropha* in nurseries are twofold: first, seedlings can grow under controlled, optimal circumstances and slow or abnormally performing plants can easily be removed. Another advantage is that nursery plants are stronger when planted in the fields and can more easily



survive when the conditions for establishment are sub-optimal (drought, weeds, presence of browsing cattle and insects). There are, however, drawbacks of nursery plants. The root development of seedlings is hampered because of growing in the smaller containers. This is especially disadvantageous when the seedlings are not planted timely in the fields (< 1 month). There are also extra labor and capital requirements, and there is the possibility of spreading pests and diseases to all seedlings and the field during planting.

A nursery is a good option in case you have very low quality seed material because the best performing plants/ seeds can be easily selected.

It is also possible to germinate seeds in larger germination beds or directly into polybags (less work). The most vigorous seeds that germinate within 10 days (at average temperatures of 23°C or higher) should be used, the others should be discarded. The selected germinated seedlings should be transferred into polybags (see figure below). In the polybags the jatropha plants can grow for a month (in full sun) or 2 months (when shaded) and should then be transferred to the fields. The plants should be provided enough soil moisture and in full sun they will need more water. All plants that show growth visibly slower than others or show abnormal growth (e.g. strangely shaped leaves) should be removed in order to increase the average plant production in the consecutive years of seed production in the field.

In Mozambique a nursery has grown seedlings in a seedbed nursery on a relatively large scale and no polybags were used. Despite the cutting of the roots when the seedlings are removed from the seedbed, the seedlings are performing well [31].

It is wise to invest in chemical pest and disease control in order to keep the seedlings free from pest and diseases that could otherwise be spread to the fields.



Figure 2. Jatropha nursery with seedlings (for appr. 2 ha.) in polybags partly shaded artificially (left) or by trees (right). pictures: Peter Moers

After the seedlings have established (1-1.5 months), they should be transferred to the field as quickly as possible. The soil requirements for planting are similar to those for direct seeding (see “direct seeding”).



2.4.6. Cuttings

Cuttings are a fast and cheap way of propagating *Jatropha*. One advantage is that cuttings are clones with the same genetic characteristics as the mother plant, and in case a high yielding mother plant is selected the cuttings have the same properties [31]. The disadvantage is that cuttings develop only lateral roots and cannot access nutrients and water in deeper soil layers. Cuttings therefore have limited drought tolerance. We recommend this only for living fences. Using cuttings for a *Jatropha* plantation only works on fertile and soils with a good permanent water supply and absence of long dry periods.

Cuttings are best made from the thickest branches at the base of the *jatropha* plant. Best is to make cuttings of at least 30 cm (but 50 cm gives a higher success rate). Cuttings should be placed directly in wet soil leaving 15 cm or more of branch above the soil. Cuttings can also be produced in a nursery in polypropylene bags. Soil should be kept wet (therefore the rainy season is the best time for cuttings). Normally the first shoots appear after 3 to 4 weeks.

2.4.7. Micro-propagated clones

A technologically advanced method of obtaining larger amounts of *jatropha* plants is by micro-propagation. The advantage is that you can create large numbers of genetically identical plants of one mother plant with the desired characteristics. Similar to cuttings, the root system development is not natural and it requires hormonal stimulation to induce roots to grow vertically instead of laterally. This method requires sophisticated technologies and chemicals and is costly and as such is not recommended for smaller scale plantations. However when good quality micro-propagated plants become available on the market at affordable prices this will be interesting for smaller plantations as well.

2.5. Plantation management (agronomy)

2.5.1. Weeding

Jatropha usually survives when overgrown by weeds, but growth and production will be minimal [31]. It is very important to keep the *jatropha* fields free from weeds. At regular intervals weeds should be removed and left on the ground to provide organic material to the topsoil. The frequency of weeding depends on the growth of the weeds. When weeds start to shade the *jatropha* or grow as tall as the *jatropha* plants they should be removed, as well as when they limit access to the space in between rows. After one to three seasons depending on the agro-climatic conditions the canopies of *Jatropha* will be so dense that weed growth is severely suppressed and labour for weeding consequently drops [31].

In most cases the amount of labour determines the area that can be kept weed-free. In the case of large-scale plantations with partly mechanized cultivation, around 2 ha/person could be sufficiently freed from weeds. In case of small-scale cultivation this is closer to 1 ha/person.

2.5.2. Nutrient management

2.5.2.1. Nutrient requirements

Jatropha needs sufficient amounts of nutrients in order to grow into a full size plant and to produce seeds.

In the first 4 years nutrients are needed to build up a good plant architecture (roots, stems, leaves). Also in this period an increasing amount of nutrients is needed to produce flowers and fruits. After 4



years, when the plants have developed to their final shape and size nutrients are primarily needed for maintenance of the plant and for fruit production.

The nutrients removed by harvesting jatropha fruit should be returned to the fields after the energy (mostly lipids consisting of the elements C, H and O and no nutrients) is extracted. Jatropha fruit shells and presscake (or residue from biogas production) are best returned to the fields as organic fertilizer, which closes the nutrient cycle. In that case, jatropha plants can continuously produce and no or little fertilization is necessary.

When fruitshells and presscake (or biogas residue) are not returned to the fields regular fertilization with NPK (nitrogen/ phosphorus and potassium) and micronutrients will be necessary.

In case of highly fertile soils, jatropha fertilization is not necessary. There are enough nutrients for plant development and fruit production. In case of poor soils fertilization

2.5.2.1.1. Nutrients requirements during jatropha establishment

In the first years, nutrients are needed for maturation and development of high-yielding jatropha plants. Under conditions of poor soil fertility extra nutrients are required for plantation establishment and seed production in the first 4 years.

Table 1 - Annual macro nutrient requirements to build up jatropha standing stock and fruits in first 4 years. [29]

Production in year 4, with 50% of required nutrients from existing soil fertility.					
Year	1	2	3	4	Total
Annual need	kg/ha/yr	kg/ha/yr	kg/ha/yr	kg/ha/yr	
N	23	34	69	103	229
P2O5	7	11	21	32	71
K2O	34	50	101	151	336

The yearly amounts of different types of fertilizer needed in the first 4 years have been calculated. This is based on the nutrient requirements given in the previous table and the nutrient content of different types of fertilizer. The requirements are calculated based on sufficient N-supply and in general the requirements for other nutrients are also met when the amounts in the table below are given. These values count for poor soils, where only 50% of the nutrients needed are derived from the soil. In case of extremely poor soils, more fertilizer is needed. The composition of chemical fertilizer in the tables is given as the amounts of Nitrogen: Phosphorus: Potassium (N:P:K) in percentages.

Table 2 - Annual amount of fertilizers requirements to build up jatropha standing stock and fruits in first 4 years. [5]

Type of fertilizer	Year 1	Year 2	Year 3	Year 4	Total 4-yr
Dry cow manure	5 MT/ha	6 MT/ha	12 MT/ha	18 MT/ha	41 MT/ha
Dry chicken manure	1 MT/ha	1.2 MT/ha	2.4 MT/ha	3.6 MT/ha	8.2 MT/ha
Vermicompost	1.2 MT/ha	1.7 MT/ha	3.4 MT/ha	5.2 MT/ha	11.5 MT/ha



Chemical fertilizer (16-4-16)	140 kg/ha	210 kg/ha	430 kg/ha	640 kg/ha	1.4 MT/ha
Urea (46% Nitrogen)	44 kg/ha	74 kg/ha	150 kg/ha	224 kg/ha	492 kg/ha

2.5.2.1.2. Nutrients requirements for seed production

A harvest of 1 MT of seeds is equivalent to the removal of the following amount of nutrients (in fruits including seeds) [3]:

- 14.3 to 34.3 kg/ha N
- 0.7 to 7.0 kg/ha P
- and 14.3 to 31.6 kg/ha K

See appendix for the withdrawal of nutrients of one ton of dry seed of jatropha compared with other oilseed crops.

In case fruitshells and presscake (or residue from biogas production) are not returned to the field, these nutrients need to be replaced. The yearly amounts of different types of fertilizer necessary per hectare to replace the nutrients removed by harvesting 1 MT of seeds are shown below. The requirements are calculated based on sufficient N-supply and, in general, the requirements for other nutrients are also met when the amounts in the table below are given.

Dry (solid) cow manure	7 MT
Dry (solid) chicken manure	1.3 MT
Vermicompost	1.65 MT
Chemical fertilizer (15-5-10)	0.22 MT (220 kg)
Chemical fertilizer (12-2-10)	0.27 MT (270 kg)
Urea (46% Nitrogen)	0.072 MT (72 kg)

2.5.2.2. Organic matter

Organic Matter (OM) level in the soil leads to an enhanced cation exchange capacity (resulting in a loose binding of nutrients in the organic matter) and also a better soil structure. It has been demonstrated in a number of trials that jatropha responds positively to a high OM level. Organic fertilizers are therefore recommended.

2.5.2.3. Fertilization

The best time to fertilize is just before or at the start of the rainy season. It is best to apply fertilizer evenly in a circle around the jatropha plant with a maximum of 1 meter from the plant. In case anorganic (artificial) fertilizer is used, it is best mixed with organic matter or compost. Applying artificial fertilizer in smaller quantities and with a higher frequency throughout the year decreases losses due to run-off and deep percolation and increases its efficiency.

Heavy nitrogen fertilization may lead to strong emissions of the greenhouse gas NO₂ with a strong global warming potential. This will reduce the number of carbon credits that can be earned in a Jatropha project.



2.5.2.4. Mycorrhiza

A simple and cheap way of increasing jatropha yields is by the use of mycorrhiza, which are fungi that live in symbiosis with plant roots. Mycorrhiza taps organic substances from the plant, especially sugars and B-vitamins. In return mycorrhiza make nutrients in the soil available for the plant and help in water uptake. Mycorrhiza, combined with moderate fertilization, guarantees a high nutrient uptake by the plant and minimizes nutrients losses by percolation. The use of mycorrhiza is cheap (about 5-10 euros/ha). Mycorrhiza are especially effective in poor and dry soils where they can increase yields by about 30%.

Mycorrhiza are best applied dissolved in water and applied in the plant hole before or during planting. Mycorrhiza can also be applied to existing jatropha plants by digging a circular pit of around 10-20 cm deep at around 40 cm around the stem and applying the water with mycorrhiza. Afterwards the pit should be covered with soil. It is also possible to coat seeds with mycorrhiza before seeding. In addition, they are easy to apply in a nursery when mixed with the water.

2.5.3. Pruning

Jatropha flowers form only at the end of branches, pruning leads to more branches and as such to more potential for fruit production. Another important reason to prune is to keep the plants in a manageable size. Under natural conditions jatropha can grow into a tree of about 6 meters tall with a crown width of 6 meters, which makes it very hard to harvest. In a plantation with a high density (around 1100 plants/ha), it is important to sufficient keep distance between the plants to avoid competition for light and space. Plants should be kept low to facilitate manual picking.

With good pruning the jatropha plants should have strong lateral branches that can bear the weight of the fruits. In the fourth or fifth year after planting and after several rounds of pruning the plants should ultimately have some 200-250 terminal branches.

It is important to prune only under dry conditions and best when the plants have shed their leaves. When pruning make slightly vertical cuts (see pictures) so water runs off and avoid making horizontal cuts where water can stack. Pruning in the rainy season and with high relative air humidity increases the risks for bacterial or viral plant infection and fungal attacks. All cut plant material can be left as ground cover or mulch.

The first pruning is needed after 3-6 months and when plants have developed well (at least 70 centimetres tall). When branching from the ground has started naturally cutting back the main stem is not necessary. Cutting the main stem is done at a height of 30-45 cm aboveground. Larger plants can be cut back at 45 cm and smaller plants at 30 cm.



Figuur 8 – Branching after pruning. photo: Arthur Riedacker



Figuur 9 – Plant cut back photo: Arthur Riedacker

After one year, a second round of pruning is needed when plants have grown extensively after the first pruning. Secondary and tertiary branches should be cut leaving about one third of branch (as seen from the last branching) on the plant.

After two years, a same round of pruning (as after one year) should be repeated.

On the longer term, after about 8 to 10 years and when plants are growing very dense, it is advised to cut back the entire plant to about 45 cm aboveground and allow it to re-grow. Because of the well-developed root system the plant will grow back very rapidly.

2.5.4. Irrigation

Irrigation can increase yields. The costs for irrigation are high and in most cases, with current jatropha seed prices, it is not economically viable. Installation and material costs for the irrigation of 1 hectare are at minimum € 400. Operational costs per mm of irrigation are in the range of € 0.30 to €0.40/ mm/ ha.

In some cases after one yield the rainy season is just not long enough to sustain a second yield. With irrigation the growth season can be extended long enough for a second yield. The returns from an extra yield are maximally around 1500 kg/ha. At a price of e.g. € 0.06/kg the extra return is € 90. When an extra 200 mm needs to be applied the costs per hectare are **at least** €60, not yet including the costs for installation of the irrigation system. Considering the extra manpower needed for harvesting, and the costs for extra fertilization one can easily conclude that the benefits do not outweigh the costs.

Therefore, under normal conditions, irrigation only makes sense in show gardens and in the production of jatropha plants for special purposes, e.g. high-quality seed production for propagation, plant breeding, clonal gardens, and scientific experiments.

2.5.5. Intercropping

The greatest advantage of intercropping jatropha with annual crops is that the farmers will apply good management of the annual crops and also for jatropha. Jatropha plants are often neglected in the first year(s) because the production is not interesting from an economic perspective.



Growing jatropha in combination with other plants is only possible when sufficient nutrients and water are available. In dry locations without irrigation, intercropping is not possible due to competition for water. In soils poor in nutrients, intercropping is only possible with extra fertilization. It is also possible to grow fodder crops in between the Jatropha plants and allow grazing. In this case the jatropha plants should be well established and tall to avoid damage caused by animals. Jatropha should not be intercropped with cassava, since it is a possible host for several cassava diseases.

It is advisable to start intercropping at the same time as planting the jatropha. Jatropha initially might grow slower than the intercropped species. In that case, and when intercropped species are planted close to the jatropha plants, it is recommended to plant the intercrops a month later so jatropha is given a head start. Intercropping with species that provide yield in the first and second year ensures good management, especially clearing the crops from weeds.

Crops that can be considered should be annual or bi-annual crops that remain relatively low and will not shade the jatropha plants. Examples are corn, peanuts, beans and peppers. After 1 or 2 years, the jatropha plant canopy closes and there is no more room for intercropped species and it becomes difficult for weeds to establish. Nitrogen fixing species such as beans are at an advantage in intercropping systems since jatropha itself does not fix nitrogen [31].



Figure 10 – Jatropha intercropped with *Arachis pinto* and *Capsicum chinensis* in Belize, photo: Sylvia Baumgart.

The models in Chapter 6 describe the economic feasibility of intercropping.

2.6. Jatropha hedges

Jatropha is also cultivated in hedges. The hedges are used as living fence, for erosion control, demarcation of boundaries and for the protection of homesteads, gardens and fields against browsing animals [12]. In hedges jatropha is often planted 25 to 50 cm apart in a single row or a double row with 50 cm between the rows [5]. It is recommended to plant about 1 jatropha plant from seed for every meter of hedge. This will ensure that water and nutrients from deeper soil layers are used [31]. On fertile soils with a good moisture supply yields are about 0.8 kg per meter of hedge [12]. On poor soils this will be much less.

2.7. Seed yields

Jatropha seed yields depend on a number of factors (see figure below):

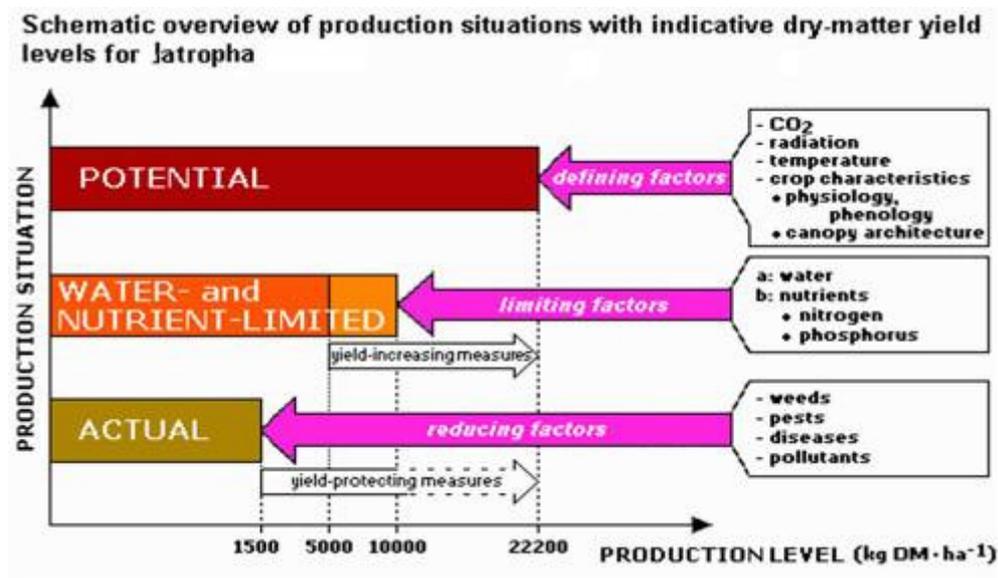


Figure 11 – Schematic overview of the production situations with indicative dry-matter yield levels. [24]

When all growth conditions are optimal and only water and nutrient levels determine jatropha yield, FACT has estimated jatropha yields and potential seed yields for different levels of water and nutrient supply (see table below). These data are meant to give an indication on yields and by no means guarantee these yields will be obtained in reality. The table is based on field data FACT has collected since 2005. The yield under optimal conditions is based on data from N. Foidl from the well-documented “proyecto tempate” (1992) in Nicaragua, with maximum yields of 4.5 MT of dry seeds/ha/year (FACT seminar on Jatropha agronomy and genetics, 2007). The 6 MT maximum yield given is based on the assumption that the breeding and selection efforts of the last years have led to higher yielding plants and the agricultural practice has been optimized.

The following considerations and restrictions apply to the aforementioned information:

Jatropha genetic material. Above-mentioned yields only apply to plants from selected seeds from the highest yielding provenances available that are adapted to local soil and climatic conditions.

Agro-ecological conditions. These figures only hold for areas with the optimal temperatures and radiation for Jatropha.

Water supply. Optimal water supply means that water is available to the Jatropha plant at all times and drought and water logging do not occur. In case of rainfall, growth is either:

> water limited (drought), gradually reducing the number of harvest from three to one harvest per year and reducing the water availability for growth and fruit production.

> limited due to negative impacts from water logging leading to root damage. This happens in case of excessive rainfall in combination with water-holding soils.

Soil fertility. High soil fertility is mentioned and also implies good soil structure and aeration.



Table. Expected Jatropha seed yields for different water supply and soil fertility [5].

Water supply	Soil Fertility	Dry Seeds (kg/ha/yr)
Optimal	high	6000
„	medium	2500
„	low	750
Normal	high	3500
„	medium	1500
„	low	500
Sub-optimal	high	1500
„	medium	750
„	low	250



2.8. Pest and diseases

Author: Flemming Nielsen

When *Jatropha curcas* grows as solitary plant in the landscape or in small stands it rarely shows signs of pests and diseases. However, when cultivated in higher densities in plantations or hedges this situation changes. Reports of pests and diseases come from all parts of the world in increasing numbers. In most cases these pests and diseases are not detrimental and so far few are of economic importance.

When a new crop is introduced and cultivated on a large scale it can take years before the pest and disease pressure is felt. This effect, for example, is demonstrated with several new agro forestry species. The low incidence rate of pests and diseases currently observed in most areas can therefore not be assumed to last [3].

Pests and diseases that have been reported to affect *Jatropha* are listed in the appendix.

Most of the pests are of minor importance. The important pests vary with regions:

- **Africa:** Flea beetle (*Aphthona* spp.) eats the leaves and their larvae penetrate the roots (Nielsen 2007, Gagnaux 2008). The yellow flea beetle (*Aphthona dilutipes*) appears to cause more severe damage than the golden flea beetle, sometimes resulting in 100% mortality. The author has only observed the yellow flea beetle in Manica Province in Mozambique and knows only of one other observation namely from Malawi where it also causes severe damage. (Timothy Mahoney, Pers. comm.).
- **Central and South America:** fruit feeding true bugs, *Pachycoris klugii* Burmeister (Scutelleridae) and *Leptoglossus zonatus* (Coreidae) (Grimm and Maes 1997).
- **Asia:** The scutellarid bug *Scutellera nobilis* Fabr. which causes flower fall, fruit abortion and malformation of seeds, and the inflorescence and capsule-borer, *Pempelia morosalis* that causes damage by webbing and feeding on inflorescences and in later stages boring into the capsule (Shanker and Dhyani 2006).

Virus damage is of major concern and appears to be spreading fast in India. In Africa virus presence is still rare.

There is concern that, for instance, African Cassava Mosaic Virus may be transferred by *Jatropha curcas*, although cases have only been reported in *Jatropha multifida*. L. Münch (1986) states that cassava superelongation disease (*Spaceloma manihoticola/Elsinoe brasiliensis*) can be transmitted to *Jatropha curcas*.

For these reasons it is advised not to plant cassava and *Jatropha curcas* in the same field (Heller 1996).

Common bean (*Phaseolus vulgaris*) is susceptible to *Jatropha* Mosaic Virus (Hughes et al 2003). It is transmitted by whitefly (*Bemisia tabaci*) (Raj et al 2008).



2.8.1. Control Measures

Research on biological control measures is ongoing, but currently there is no knowledge about the efficiency of various methods, so specific recommendations cannot yet be made (Grimm 1999, Raj et al 2008). However, methods that work with other crops may be efficient in *Jatropha* too. It is also likely that local methods can be developed in many cases so experimentation is encouraged.

Chemical pesticides are used successfully against major pests in *Jatropha curcas*, including:

- Pesticides containing Chlorpyrifos or Cyphenothrin are efficient against *Apthona* spp. (flea beetle) (F Nielsen pers. obs.)
- Captafol at 3000 ppm is recommended as a dip for the eradication of super elongation disease (Lozano et al 1981) in cassava cuttings. It is likely to be efficient for *Jatropha* too.
- Collar rot can be controlled with 0.2% Copper Oxy Chloride (COC) or 1% Bordeaux drenching (FACT Seminar 2007)
- Bark eater (*Indrabela* sp.) and capsule borer can be controlled with a mixture of vitex, neem, aloe, Calatropis or Rogor @ 2 ml/lit of water. Alternatively, spraying Endosulfan @ 3 ml/lit of water can be used (Paramathma et al 2004, FACT Seminar 2007). Many countries have banned endosulfan.

2.8.2. Preventive Measures

1. Use resistant *Jatropha* varieties. Presently there is no systematic knowledge about resistant varieties. However, non-diseased plants should be selected as "mother plants" for seeds and cuttings.
2. Don't plant *Jatropha curcas* when the pest pressure is high. High pest pressure is normally found towards the end of the rainy season when temperatures and the relative humidity is high. A recent study (Gagnaux 2007) found that *Jatropha curcas* planted when the pest pressure was high showed increased infestation rates years after planting.
3. Sanitary measures:
 1. Disinfect tools used for cutting and pruning. Alcohol, chlorine and household cleaners like Lysol are quite efficient but may not be feasible for small farmers. Cleaning with water, grass or sand is not very efficient for removing latex but is better than nothing. If a fire is available flaming may be the most efficient low-cost method.
 2. If possible avoid using the same cutting & pruning tools for cassava and *Jatropha*.
 3. Uproot diseased plants. Inspection should preferably be done at least weekly during the first few months. If nurseries are used, inspection and "rogueing" should be part of the routine. Whiteflies, which are responsible for spreading important viruses, do not feed on wilted leaves, so they will usually not touch uprooted plants. However, there are other factors, so it is advisable to dry the uprooted plants at a distance from the field or to bury or burn them.
 4. Minimise damage to the *Jatropha* plants to reduce the risk of microorganisms entering. Prune with sharp tools only and always cut at an angle. Avoid creating horizontal cuts where water will drain slowly.



4. Large dense stands of any crop increase the incidence of pest and diseases. Try to use:
 1. Wider spacing e.g. 3 by 3 or row planting with at least 4 m apart
 2. Many small fields separated and isolated from each other in the landscape
 3. Boundary planting instead of plots
 4. Mixed cropping
5. *Jatropha presscake* has pesticidal properties and can be useful as a pesticide to protect recently established *Jatropha* because young *Jatropha* plants have low levels of toxins.

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