Euphorbia tirucalli Bioenergy Manual

Feedstock production, bioenergy conversion, applications, economics

Version 2

Photo: Ecoenergy B. G.

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TABLE OF CONTENTS

1 INTRODUCTION

1.1 BACKGROUND

This manual has been prepared to support practitioners in growing *Euphorbia tirucalli* (ET) plants as an energy crop. Use of ET as a feedstock for bioenergy is still experimental and more information on its feasibility and use as an energy crop will be added to this ‘living document’ with time.

E. tirucalli can be of great importance as a bioenergy source in developing countries in the tropics. As a crop it is easy to establish and manage and the whole plant can be harvested all year round as a feedstock for bioenergy without having to wait for flowers or fruits. ET can withstand severe drought without problems.

Especially in areas that are not connected to an electricity grid and rely on expensive electricity generated from fossil fuels ET can be of importance. It is possible to convert the plant into biogas and the effluent that is produced can be used to fertilize the plots that have just been harvested. This creates a virtually closed nutrient balance reducing the need for external fertilization.

Originally ET was known as petroleum plant and Nobel Prize winner Melvin Calvin included the plant in his research on hydrocarbons produced from vegetative origin. More recently, progress was made on ET biomass production by Ecoenergy B.G. and the potential to produce biogas was assessed by FACT Foundation.

1.2 BIOENERGY POTENTIAL OF *EUPHORBIA TIRUCALLI*

This biomass possibly has the highest yield of all known energy crops. *E. tirucalli* is a unique example of a plant combining permanent crassulacean acid metabolism (CAM) stems with short-lived C_3 leaves. During humid spells when leaves are present, this combination allows high CO_2 uptake and, thus, elevated growth rates. It is a low-input plant, with high drought and salinity tolerance that can be grown on land that is not suitable for most crops. It has the potential to provide semi-arid zone inhabitants with an energy solution in the form of a biomass that can be converted to gaseous, liquid or solid biofuels.

More research is needed and should cover crop genetic improvement, improved farming techniques to intensify production, improve the product quality, and develop efficient technologies to extract and use the biofuels.

FACT Foundation is currently developing a pilot project for biogas production and use from ET.

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ET and Leidy Gisela of the
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3 ABBREVIATIONS

2, 4, 5-T	2,4,5-Trichlorophenoxyacetic acid, a synthetic auxin
B5	Gamborg's B5 vitamin mix to be used in solid substrate culture medium for microbiological work
BMPs	Best Management Practices
°C	Degrees Celsius
CCC	Cycocel or chlormequat, a plant growth regulator
CIAT	International Center for Tropical Agriculture
cm	Centimeter
CO_2	Carbon dioxide
CRC	Corporación Autónoma de Cauca (Colombia)
DM	Dry matter
Ecoenergy B.G.	Ecoenergy Business Group Ltda.
e.g.	exempli gratia, for example
et al.	et alii, and others
EDTA	Dethylenediaminetetraacetic acid
ET	*Euphorbia tirucalli*
FACT Foundation	Fuels from Agriculture in Communal Technology
FAO	Food and Agriculture Organization of the United Nations
Fig.	Figure
g	Gram
GA_3	Gibberellic acid
H	Hour
Ha	Hectare
ie	id est; that is to say; in other words
IAA	Indole-3-Acetic Acid, a phytohormone
IBA	Indole-3-butyric acid, auxin, a plant rooting hormone
ICA	Instituto Colombiano Agropecuario
ICRAF	World Agroforestry Centre
Kg	Kilogram
kJ	Kilojoule
kWh	Kilowatt hour
L	Liter
LS	Linsmaier-Skoog culture medium
m	Meter
Mg	Milligram
mm	Millimetre
MT	Metric ton, an alternative term for tonne, a measurement of mass equal to one thousand kilograms
NAA	1-Naphthaleneacetic acid - synthetic auxin, an organic compound and plant hormone
NPK rating	Or N-P-K, is used to label fertilizer based on the relative content of the chemicals nitrogen(N), phosphorus(P), and potassium(K) that are commonly used in fertilizers.
pH	A measure of the acidity or basicity of an aqueous solution
ppm	Parts per million

4 EUPHORBIA TIRUCALLI BIOMASS PRODUCTION

4.1 BOTANICAL DESCRIPTION

4.1.1 General

Euphorbia tirucalli L. is a succulent, cactus-like (FAO) spineless, unarmed[1], much-branched, monoecious[2] or more often dioecious[3], easy to recognize, perennial shrub or tree up to 10–15 m tall.

The provided description from 4.1.2 to 4.1.6 has been taken from Voigt and Porter, 2007.

The plant has unmistakable, brush-like branch masses (**Fig. 1 and 2**) that are a noticeable feature of the plant (Voigt and Porter 2007) and has the following characteristics in common with other species of the genus Euphorbia (Corman 2001):

- Latex or white sap, sticky and irritating;
- Flowers small and insignificant called Cyathea, complemented by nectariferous glands[4] and bracts[5];
- A fruit with three capsules each containing a single seed, which shines when ripe and expels the seeds away.

[1] Having no spines, thorns, or similar structures.
[2] Plants which bear both sperm and eggs on the same gametophyte.
[3] Gametophytes produce only sperm or eggs but never both.
[4] Possessing nectarines.
[5] Modified leaves growing just below a flower or flower stalk.

 

Fig. 1 and 2. Brush-like branch masses that are a noticeable feature of the plant (Photos: Ecoenergy B. G.).

4.1.2 Trunk or Stem

The rubber-hedge euphorbia reach usually 2-5 m but may grow up to 15 m on occasion with a 2-4 m spread (Voigt and Porter 2007). The main trunk and branches are woody and brownish and may thickening up to a diameter of 25 cm. ET grows with single or multiple trunks (**Fig. 3 and 4**). The bark (**Fig. 5 and 6**) of very old specimens is grey and rough with longitudinal dents and ridges that break up into very small fragments. There are sometimes conspicuous[6], small protuberances[7], such as a bulge[8], knob[9], or swelling, on the bark, and occasionally black, rough, crosswise bands.

[6] Easy to notice; obvious.
[7] Things that bulges out or projects from their surroundings.
[8] An outward curve.
[9] A rounded projection from a surface.

Fig. 3 and 4. Multiple stems of one plant of *E. tirucalli* (Photos: Ecoenergy B. G.).

Fig. 5 and 6. The trunk (**A**) and bark (**B**) of an old tree (Photos: Ecoenergy B. G.).

4.1.3 Branches

E. tirucalli is a plant very branched with branches often arranged in pseudo whorls[10] forming brush-like masses that are the best known feature of this species.

[10] An arrangement of three or more branches radiating -coiling or spiraling- from a single node.

The thin twigs are pendant (hanging down), pale green and occur opposite each other, alternate or in groups on the branchlets which gives a rather untidy and rounded appearance to the crowns. Branchlets brittle succulent, 7 mm thick often produced in whorls, green and longitudinally fine stripes and very small leaf scars, with copious white to yellowish latex. The extreme tips of young leafy branchlets are sparsely short-hairy (Voigt and Porter 2007).

Younger branches are usually leafless, succulent, rich in latex, green or light green, smooth, brittle, and cylindrical, 5-8 mm in diameter, looking like so many pencils, fingers or breadsticks. Leaf scars on young twigs form conspicuous dents which contract until they are no more than grey dots on older branchlets and can even be seen on fairly thick green stems (**Fig. 7**). Plants are without spines.

Fig. 7. Leaf scars on young twigs (Photo: Ecoenergy B. G.).

4.1.4 Leaves

Leaves are rarely seen as they fall very early o quickly (early deciduous), tiny, few, simple, fleshy, small or minute, slender and alternate (**Fig. 8 and 9**). The leaf blade is linear-lanceolate[11] to oblanceolate[12], 1–2.5 cm long, ca 3–4 mm broad and 2 mm thick, acute at tip,

[11] Lance-shaped.
[12] Top wider than bottom.

tapered to the sessile base[13], arranged spirally, present only at the tips of young branchlets. The extreme tips of young leafy branchlets are sparsely tomentose[14], with curled brown hairs, and soon glabrescent[15]. Stipules[16] are minute, glandular and dark brown. The function of the leaves is taken over by the green branches.

Fig. 8 and 9. Fig. 8, Leaves; **Fig. 9,** some older –red– leaves of ET (Photo: Ecoenergy B. G.).

4.1.5 Flowers

Plants are monoicous or dioicous[17], the chromosome number is 20 and the diploid number[18] is 2*n*.

What is usually called the flower, or inflorescence, is really a group of petal-like bracts[19]. The true flowers, which are centered within the bracts, are inconspicuous[20].

The flowers are small or very small, yellow, green or pink arranged in groups on the terminal branches, discreet, and grouped at the top of the short branches, in heads, stalkless at the end of twigs, and carried in clusters at the apex of the short branches or in the angles of branches (**Fig. 10-13**).

[13] The leaf blade attaches directly to the stem.
[14] Plant hairs that are flattened and matted.
[15] Losing hairs with age.
[16] Outgrowths borne on either side of the base of a leafstalk.
[17] Botanical term used to describe plants which bear both sperm and eggs on the same gametophyte. Dioicous is the complementary term describing species in which gametophytes produce only sperm or eggs but never both. A gametophyte is the haploid, multicellular phase of plants and algae that undergo alternation of generations, with each of its cells containing only a single set of chromosomes.
[18] Having two sets of chromosomes, one from the male and one from the female.
[19] Modified leaves.
[20] Not easily noticed or seen.

More detailed, flowers consists of a terminal umbel-like[21] cyme[22], grouped 2 till 6 together at the apex of branchlets, each forking 2 up to 4 times, composed of dense clusters of flowers, each cluster called a 'cyathium'. ET develops only male flowers (but sometimes with a few female flowers), or fewer cyathia (false flowers), almost sessile[23] and unisexual[24].

Male flowers with linear bracteoles (small bracts), plumose at apex, and stamen which are approximately 4.5 mm long with cup-shaped, glands, up to 1.5 mm × 2 mm, yellow or bright yellow, lobes triangular, and approximately 0.5 mm long.

Female flowers, involucres small bracteoles, and styles are approximately 2 mm long, 3-celled, united at the base, with pedicel up to 10 mm long in fruit, hairy, perianth[25] distinctly 3-lobed, lobes approximately 0.5 mm long, ovary superior, fused at base, with thickened deeply bifid[26] recurved stigma. Bracts, are approximately 2 mm long, rounded, 2 x 15 mm sharply keeled, and usually glabrous[27] except on the margin. An aborted female flower is occasionally present.

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[21] An inflorescence which consists of a number of short flower stalks -called pedicels- which are equal in length and spread from a common point, somewhat like umbrella ribs.
[22] An arrangement of flowers in a plant inflorescence, glabrous or tomentose, with curled brown hairs, especially the involucres and lobes.
[23] Subsessile, the leaf blade attaches directly, or almost directly, to the stem.
[24] Only female flowers developing.
[25] Outer, sterile whorls of a flower.
[26] Divided into two lobes by a median cleft.
[27] Bald, hairless.

Fig. 10-13. Flowers of the petroleum plant (Photos: **Fig. 10-12,** Ecoenergy B. G.; **Fig. 13,** Carol Cloud Bailey; Cloud, 2006-2011).

4.1.6 Fruits

Fruits are tripartite capsules[28] and a capsule measures about 8-12 mm in diameter, is subglobose (nearly globose), almost glabrous[29] or glabrescent[30], longitudinally very slightly lobed, short-stalked (8 mm), bent at an angle, pale green, with a pink tinge and conspicuously

[28] Divided into three parts, 3-seeded.
[29] Without hair.
[30] Losing hairs with age.

pubescent (soft hairs). Capsules dehisce while still on the tree, and exserted[31] on a tomentose pedicel[32]to 1 cm long (**Fig. 14-16**).

Fig. 14-16. Fig. 14, Fruits in full formation, shortly after being fecundated (Photo: Werner Voigt and Harold Porter, Voigt and Porter 2007); **Fig. 15 and 16,** Mature fruits (**Fig. 15,** Jesús León Garrido; León; **Fig. 16,** Ecoenergy B. G.).

4.1.7 Seeds

The seeds are ovoid (oval), about 3-4 mm x 2.8-3 mm, glabrous, smooth, buff speckled with brown and with a dark brown ventral line (with a white line), around the small white caruncle[33] 1 mm across (dominute) (Club de Jardín y Naturaleza de Oaxaca de Juárez; Corman 2001).

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[31] Projecting beyond the corolla of a flower.
[32] The stalk bearing a single flower of an inflorescence covered with densely matted filaments.
[33] Fleshy wart near the hilum of the seed.

4.1.8 Latex

This species contains large quantities of latex which is freely exuded by the twigs, branchlets and stems at the slightest injury. The latex is a caustic milky white sap when damaged, like many other Euphorbia species (**Fig. 17-19**).

Fig. 17-19. ET, petroleum plant, contain large quantities of latex which is freely exuded by the twigs, branchlets and stems at the slightest injury (Voigt and Porter 2007, Photos: Ecoenergy B. G.).

4.1.9 Root system

ET that is grown from seeds is expected to develop a deep taproot, as in common as well in other Euphorbiaceae species, i.e. Jatropha. When grown from cuttings, as is most common, the plant produces lateral roots that do not grow very deep. It has to be noted that seeds of ET do not germinate easily. The plant is sufficiently water tolerant to survive drought without a taproot, therefore propagation by cuttings is a good method.

Fig. 66. Root system of a three year old plant (Photo: Ecoenergy B. G.).

4.2 AGRO-ECOLOGICAL CONDITIONS

4.2.1 Habitat

E. tirucalli occurs over the widest geographical distribution of all local euphorbias, it grows ranging from Tropical Thorn to Moist through Subtropical Thorn to Moist Forest Life Zones (Duke 1983). ET or milk bush is a shrub that grows in semi-arid tropical climates and is very well adapted to semi-arid conditions, but also occurs in both dry and moist forest, hot savannah conditions and shrub land, and withstands salt stress associated with coastal conditions, but no frost.

It is well represented in various habitats. It is normally found in dry bushland thickets, savanna-type vegetation, naturalizes easily in brushwood, open woodland, grassland, grassy hills, rocky outcrops and ridges, along river courses, bushveld and open savanna (Voigt 2007, Duke 1983). Dense thickets, for example in South Africa, are associated with this species and the plant itself may form hedge-like barriers. It occurs from sea-level up to 2.500 m altitude (Grace 2008). In Africa it is commonly associated with human settlements and becomes naturalized rapidly (Voigt and Porter 2007, Calvin 1980).

4.2.2 Climate

These plants increase their biomass promptly in semi-deserts (Maugh 1976). *E. tirucalli* grows moderately fast and thrives in moderate to warm climates and tolerates mean annual temperatures of 21 to 28 °C (Calvin 1980). Occasionally ET has been observed tolerating -2 °C, but pencil tree cannot tolerate prolonged freezing temperatures (Christman 2000) and the temperature must not drop below 7 °C below which no growth takes place (Corman 2001).

It is very drought resistant, withstanding long dry seasons. *E. tirucalli* can survive in dry all summer, but in times of growth, regular watering is appreciated. The plant tolerates annual precipitation from 250-5.000 mm

Pencil tree grows and develops best at high light intensities, like direct sun (Corman 2001).

4.2.3 Soils

ET appears to grow on almost any soil type. The associated geology varies from granite, sandstone, rhyolite[34] and stones. It grows well on a wide variety of light-textured, neutral to acidic soils with good drainage. ET has shallow roots when grown from cuttings. When grown from seeds roots are expected to grow deep as is common with species from the Euhporbiaceae familiy, like *Jatropha curcas* and cassava.

[34] Volcanic rock formed through the cooling and solidification of magma or lava, silica-rich in composition

The plant grows well at pH 6 to 8.5 and is highly tolerant to high salt content and is sometimes grown in gardens near the sea beach in gardens (Christman 2000) (see **Fig. 20**). The plant can withstand to just under 5.000 p.p.m. arsenic[35] (Barnes 2009).

Fig. 20. ET plants a few meters from the beach in Salinas, Province of Santa Elena, Ecuador indicating it is resistant to high salt concentrations in the soil and air (Photo: Ecoenergy B. G.).

4.2.4 Threats

Wild ET is threatened by habitat degradation, fire and habitat clearing for charcoal. ET is a tough plant that survives changes such as deforestation, drought and advancing deserts, where other plants cannot. In fact, seems to thrive in the midst of devastation and is spreading in the hard red clay soil (**Fig. 21 and 22**).

[35] Arsenic is a chemical element and occurs in many minerals, mainly combined with sulfur and metals, and also naturally in the native (elemental) state. Arsenic is notoriously poisonous to multicellular life.

 

Fig. 21 and 22. ET plant in a soil characterized by a high content of aluminum[36] in Dagua, Valle del Cauca, Colombia (Photos: Ecoenergy B. G.).

[36] The pH between 5.1 and 5.5 is considered strongly acidic, aluminum toxicity and deficiency of phosphorus, calcium, magnesium, nitrogen and exchangeable aluminum can occur. The average content of exchangeable aluminum is 0.74 mg/100 g in soils, as shown in the photos, and the aluminum will become more soluble and can eventually reach toxic levels for crops. To neutralize the exchangeable aluminum it is necessary to make amendments, as the aluminum ions are exchanged with phosphates to form insoluble compounds not usable by plants (CRC).

4.3 SELECTION, PREPARATION OF PLANTING MATERIAL AND REPRODUCTION TECHNIQUES

4.3.1 Introduction

ET or petroleum plant is sometimes propagated by seed, but usually by stem cuttings, and establishes quickly on almost any soil. In this Section we describe the types of propagating material and its reproduction. The planting of the material directly into the field is described in **Section 4.5 “Cropping System Establishment”**.

4.3.2 Sources of Plant Materials

The best option is to select planting material of different genetic accessions to evaluate the characteristics of each material and then select those having the best features. Occasionally, petroleum plants are found in the region and agronomists, ornamental growers, botanists, researchers or extension agents sometimes know where plants are growing. The most common sources of plant materials are hedges and ornamental plants. We recommend you use photos from this document to ask where plants are grown locally.

4.3.3 Health of Propagation Material

It is important to use petroleum plant stem cuttings from healthy plants. The following guidelines will assist you to avoid -or reduce the rate of- infected stem cuttings and to select healthy planting material for a healthy petroleum plant crop. In comparison to other crops only a few pests and diseases of petroleum plant are reported stem-borne and spread by distribution, sale, and planting of infested or diseased stem cuttings. Read the **Section 4.6.4 “Pests and Disease Management”** about how to recognize biotic stress to petroleum plant.

4.3.4 Vegetative Propagation by Cuttings

By multiplying plants using cuttings, the obtained plants will be genetically identical to the plant from which cuttings were recollected with all its virtues or genetic defects. It is the most common method of reproduction of the petroleum plant because in general these plants propagate easily through rooting the cuttings.

4.3.5 Multiplication rate

Calvin notes that cuttings with a longitude of 5 cm increased one-thousand fold in one growing season, attaining more than 50 cm height in the first growing season (Calvin, 1980).

Own observations are indicating an average multiplication rate of stem cuttings of approximately 1,280 in a 3 year period (**Fig. 23 and 24**).

Fig. 23 and 24. Fig. 23, 30 months old petroleum plant grown by planting a 15 cm long stem cutting; **Fig. 24,** Stems (Photos: Ecoenergy B. G.).

4.3.6 Collection of Cuttings

Stem cuttings should be collected from mature plants, of at least one year old. Cuttings from the apical and middle portions can present 100 percent survival rate.

To obtain stem cuttings we suggest to follow the next steps. With a sharp knife, machete or pruning scissors previously disinfected with a bleach / water solution[37] branches should be cut in the field, making smooth cuts, without breaking the stems.

You cannot harvest too many cuttings of each mature plant. You should leave a certain amount of branches and stems to prevent that the plant will not recover. **Fig. 25 and 26** show trees that were pruned to collect cuttings about three years ago.

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[37] 2,6% of sodium hypochlorite. To prepare the solution to disinfect a machete we recommend to mix 520 ml of household bleach (e.g. 5,5% sodium hypochlorite) with 480 ml of water.

 

Fig. 25 and 26. Fig. 25, These trees of ET were intensively pruned to collect stem cuttings; **Fig. 26,** After three years a good recovery of the pruned trees can be observed (Photos: Ecoenergy B. G.).

Do not recollect old branches. Once cut the branches these should be kept in the shade and afterwards the cuttings can be prepared (**Fig. 27**). Subsequently the wounds of the stem cuttings can be healed by drying, keeping the plant material during one or two days in the shade in a dry place. This may favor the formation of roots and prevent the cuttings from rotting. Cuttings smaller than 25 cm should be planted in the nursery, larger cuttings can be planted directly in the field.

Fig. 27. Preparation of stem cuttings from ET (Photo: Ecoenergy B. G.).

4.3.7 Types of Cuttings

You can collect cuttings from three parts of each plant:

1. The top section of each relative thick main branch, with small lateral side stems.
2. Sections of the thick main branch, with at least one small lateral side stem.
3. Small lateral side stems.

Fig. 28-33 show the different types of cuttings. Top portions of the main branches sprout and ensure plant vigor better than the short, young, green lateral side stem sections.

Fig. 28-33. Fig. 28 and 29, The top sections of the main branches including small stems; **Fig. 30,** Section of the thick main branch with small lateral side stems; **Fig. 31-33,** Small lateral side stems (Photos: Ecoenergy B. G.).

4.3.8 Size of Cuttings

Cuttings measuring around 15 cm in length will give an optimal growth of the plants. The diameter of the stems should be at least 0,5 cm, or thicker. Cuttings should be minimum 10 cm long and can measure up to 1 m long.

4.3.9 Transport of Propagation Material

To transport planting material from one region to another it is recommended to apply for a phytosanitary certificate. An inspection of the mother plants before collecting the plant material by a phytopathologist is useful and in many countries it is a requirement by law. The preparation of a phytosanitary certificate generates lots of benefits because you will reduce the risk of diseases and pests, and more important, to motivate the field workers and staff to implement Best Management Practices (BMPs). It is advisable to carry the branches and cuttings separated from the driver and his passengers to reduce the risk of allergic reactions.

4.3.10 Planting in the Nursery or in the Open Field

If planting conditions in the field are excellent, especially if the soil is wet, the relative large cuttings can be planted directly in the field. Large cuttings grow with ease, rooting quickly to form dense bushes which if left soon become naturalized and forms small trees (ICRAF). You can usually plant cuttings taken from the upper parts of the mother plants directly in the field because it has sufficient reserves to survive and form roots. If field conditions are (still) not optimal, it is recommended to plant cuttings in plastic (polythene) cups or bags in a nursery to avoid loss of seed material in the field.

4.3.11 Rooting Substrate in the Nursery

A coarse sandy medium or soil and organic manure (4:1 weight/weight) in a nursery bed, polythene bags or cups is ideal for planting the cuttings. To insert the cuttings in the soil, a cone or a stick can be used. After introducing the cuttings in the planting hole the soil should be pressed gently so that the cuttings are fixed.

4.3.12 Rooting Conditions in the Nursery

The polythene bags or plastic cups, planted with stem cuttings, can be kept under the canopy of, for example, a Eucalyptus tree (Behera et al. 1994). After planting the cuttings the soil should be kept moderately humid by watering regularly, once or twice a day. Recently planted fresh cuttings must be kept in a warm (approximately 25 °C) and moist area. A high temperature of the soil favors the formation of roots. It may occur that some cuttings do not generate roots or the basis of the stems rot. If this happens lost cuttings must be replaced with new ones. See also **Fig. 34-43.**

Fig. 34-36. Multiplication of petroleum plant in plastic drink cups and plastic polyethylene bags (Photos: Ecoenergy B. G.).

Fig. 37-39. Multiplication of petroleum plant in plastic drink cups and plastic polyethylene bags (Photos: Ecoenergy B. G.).

Rooting is easy but if the propagation by cuttings results in significant losses one or more of the following recommendations can be implemented:

1. Stop the flow of latex that occurs after removal of the cuttings before planting in the substrate. To succeed this, the wounds can be washed immediately using a wet sponge or cloth under running water to remove excess latex. The water will coagulate the latex. Following the washing the cuttings can be cured in a dry place. The colder the water, the more effective coagulation (Mwine et al. 2010).
2. Use a fungicide (e.g. sulfur[38]) on fresh wounds before planting the cuttings in the rooting substrate.

[38] Sulfur is a product that is found in nature and is known to have low toxicity to human and animal health. The World Health Organization classified sulfur as slightly toxic (Category III)

3. Treat the wounds of the cuttings just before planting by a rooting agent (commercial rooting powder), hormone or growth regulator. It is reported that cuttings treated with Indole-3-Acetic Acid (IAA) showed the longest root length (Kumar 2009).

4.3.13 Transplant to the Field

After the emergence of roots, which can occur between 15 and 50 days, cuttings should be transplanted at the time of the year that promotes plant growth, ie during the rainy seasons.

Fig. 40 and 41. Members of the indigenous community Wayuu planting petroleum plant for biofuel production in the nursery and in the field in Puerto Virgin, Guajira, Colombia (Photo on the left: Ecoenergy B. G.; Photo on the right, Emilio López King, Nextfuel).

Fig. 42 and 43. Fig. 42, Plantlet from the nursery (Photo: Tenemosturepuesto.com); **Fig. 43,** Direct planting of stem cuttings in the field (Photo: Ecoenergy B. G.).

(Cornell University, 1995). Additional, the sulfur will take part in the processes of plant development to be a nutrient.

4.3.14 Reproduction by Division

Similar to the reproduction by cuttings, reproduction by division allows the production of plants genetically identical to the mother plants.

Petroleum plant is separable because in general each plant contain an assembly of several stems, semi-detached with its own roots. The stems with roots can be separated in plants by cutting the stems in individual plants which than can be planted. It is recommended to use a sharp, disinfected machete to separate the plants that form a tight group. You should cut the stems to approximately 30 cm in height before lifting the plant from the earth. You have to make a clean cut, so we get several plants or stems with roots and buds in a good condition.

After conducting these divisions, the wounds can be healed for a few days. You can also apply some type of fungicide (sulfur is recommended) to prevent fungal growth. Once the wounds healed, the plants can be transplanted in the open field. This method is not easy to realize if plants are older and more lignified.

4.3.15 Sexual Reproduction by Seeds

Multiplication of petroleum plant by seeds is more complex and useful to generate new genetic material. The seed-breeding system of petroleum plant is unusual because there is not, to our knowledge, a petroleum plant breeding program. We have noticed that there is no marketing of ET seeds. Petroleum plant flowers according to the environmental conditions. Plants usually produce male flowers. Female flowers or plants are much less common. Pollination is by insects (**Fig. 44**). Monoecious plants with both male and female flowers also occur, although the female flower apparently often aborts. Germination is epigeous in petroleum plant (**Fig. 45 and 46**).

Fig. 44. Pollination of ET is by insects, in the photo a wasp.

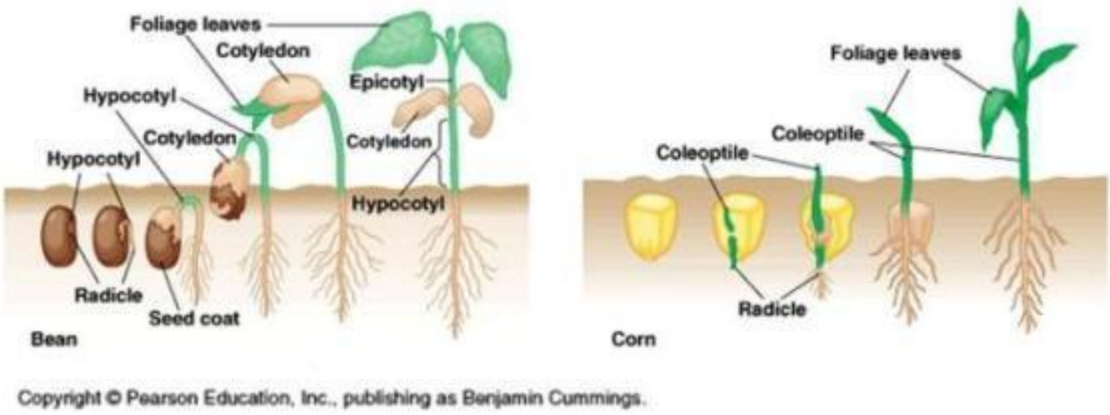

Fig. 45 and 46. Germination of petroleum plant is epigeous[39], similar to e.g. bean (Pearson Education).

The main difficulty in obtaining seeds of dioecious species is because there must be at least one male and female plant. Although flowers are pollinated by insects, it is recommended to transfer with a brush the pollen from the stamens on the pistil of the female plant. There is no information on whether the seeds of ET quickly reduce their viability. To obtain the seeds they must be cleaned thoroughly with water to reduce the risk of mildew. Dry the seeds and store them in a cool place in a paper envelope. They can also be stored in the least cool section of the fridge. There is no information on the need to stratify[40] the seeds of ET, but for a tropical plant this is highly unlikely. Please look at **Fig. 10-16** to see how the flowers, fruits and seeds look like.

Before sowing the soil of the containers should be moistened. You can sow the seeds individually 0,5 cm below ground. It is also possible to leave them on the substrate and sprinkle a fine layer of sand. If you maintain the proper heat and humidity seeds begin to germinate. To germinate they need a minimum temperature of 15 or 20 °C, although the ideal temperature is between 20 and 30 °C, and slightly less after germination.

[39] The germination of a seed in which the cotyledons emerge above the surface of the ground.
[40] Subject the seeds to a cold treatment for several weeks up to several months at around 4°C.

4.3.16 Micropropagation

Petroleum plant can also be multiplied through micro-propagation. There are some reports of in vitro propagation.

Uchida et al. (2004) reported the first successful plant regeneration from internode explants of petroleum plant. Adventitious buds were efficiently induced on Linsmaier and Skoog's medium (LS medium) supplemented with 0.02 mg/L thidiazuron (TDZ). On average of four experiments, 17.3 adventitious buds were induced from 12 explants on this medium. The adventitious buds grew into shoots during subsequent cultures on a hormone-free LS medium. For rooting treatment, shoots were cultured on the LS medium containing 0.02 mg/L Naphthalene Acetic Acid (NAA), followed by on the half-strength LS medium without vitamins, and were successful to obtain whole plantlets (**Fig. 47-51**).

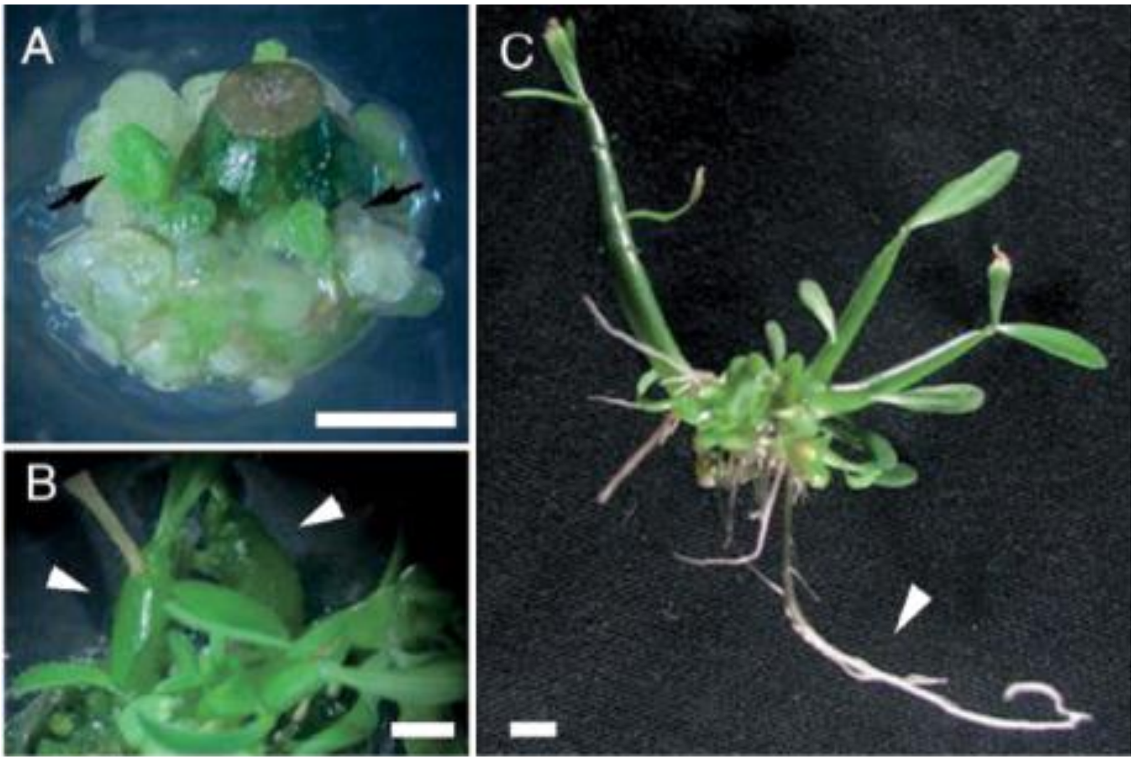

Fig. 47-49. Plant regeneration from internode segments of petroleum plant. **A,** Adventitious buds (indicated by arrows) developed after a 5-week culture on LS medium supplemented with 0.02 mg/L TDZ; **B,** Trunk-shaped shoots (indicated by arrowheads) with expanded leaves developed after 4-week culture of the explants with adventitious buds on hormone-free LS medium; **C,** A whole plantlet developed from trunk-shaped shoots after a 3-week culture on LS medium supplemented with 0.2 mg/L NAA, followed by a one-week culture on the half-strength of hormone-free LS medium without vitamins. Arrowhead indicates a root. The white bar measures 3 mm (Uchida et al., 2004).

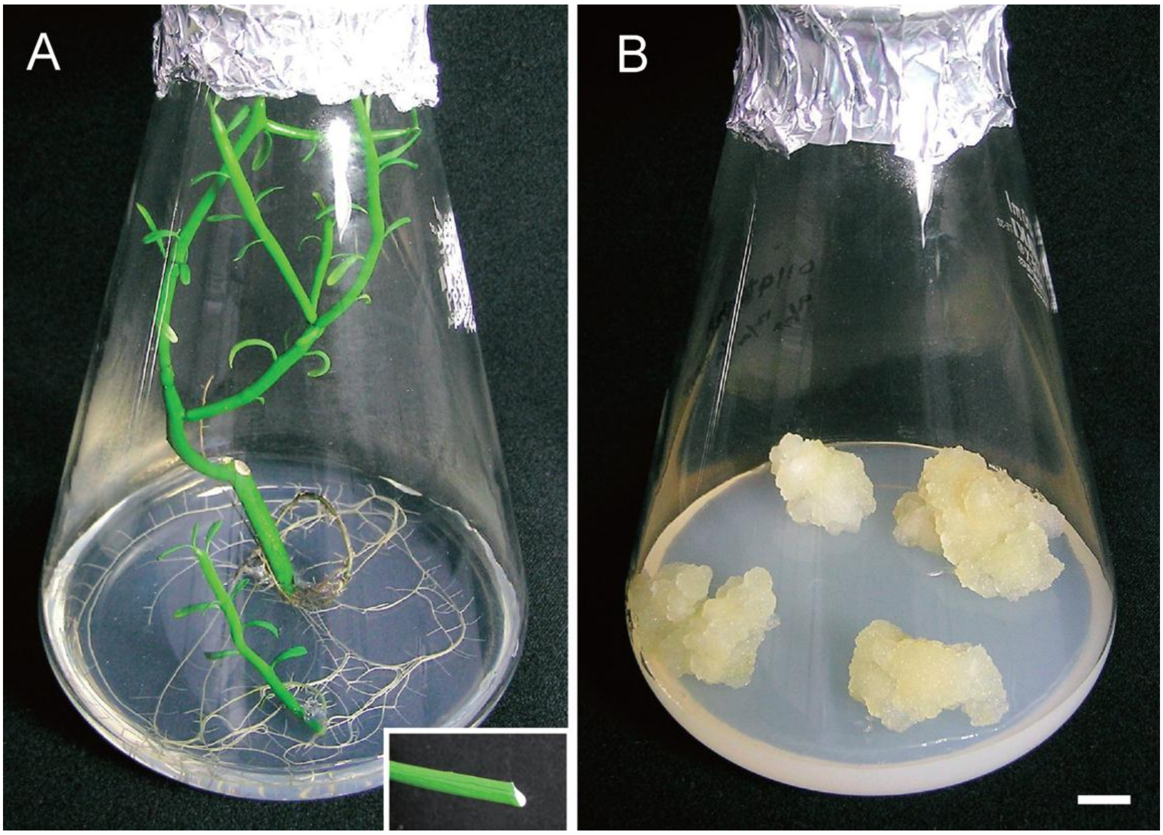

Fig. 50 and 51. A, *In vitro* culture and callus of petroleum plant. Potted plants were sterilized, and an *in vitro* culture was obtained. The inset shows a latex-exuding stem, immediately after it has been cut. The internodes of the *in vitro* plants were inoculated onto B5 agar medium supplemented with 2 mg/L NAA, 1 mg/L 2,4-D, and 0.22 mg/L 6-benzyladenine; 2,4-D every month. **B,** After successive cultures, white callus was obtained. The bar represents 1 cm (Uchida et al. 2010).

4.3.17 Management of Seedlings

During the growth of the seedlings in the nursery, every two weeks it is advisable to mix in the irrigation water, a small amount of liquid fertilizer. To transplant the seedlings to the field they should have a good size and a well developed root system. Before transplanting leave the soil to dry then afterwards extract the plantlets taking care not to damage the roots and remove soil or sand that are stuck to the roots. Subsequently introduce the plantlets into the soil (Botanical-online SL 2009-2011).

4.4 PRODUCTION SYSTEMS

4.4.1 Hedges

Petroleum plant can be planted very closely, coppiced, trimmed and top-pruned to establish a living fence or hedge (**Fig. 52-54**) (Grace 2008 FAO).

Growing hedges is a common cultivation system in Africa (Grace 2008) and Indonesia (FAO). The advantages of planting petroleum plant as a hedge are several: it does not occupy more agricultural area, it is a hedge which means that cattle and other animals have difficulty passing through the fence and an efficient management of weeds because of the shade. A disadvantage is the risk that people who pass by can cut stems and thus risk allergic reactions because of the latex that is released.

4.4.2 Intercropping and Mixed Cropping

We do not know that petroleum plants are grown in combination with other crops. However, it is commonly found in tropical regions that petroleum plants are grown in gardens as permanent species planted together with other ornamental plants. Universidad Surcolombiana and Ecoenergy B. G. established a field trial in Huila (Colombia) combining *Jatropha curcas* with ET. (see **Fig. 55 and 56**). At the Eastern Plains of Colombia (Los Llanos Orientales), an ally of Ecoenergy B. G. planted about 50 petroleum plants at a low density combined with grass and Devil's Backbone (*Pedilanthus tithymaloides*, personal communication Olivier Bouillaud and Joaquin Umaña). We have no information yet on the productivity of this system.

During the first 6 months of the establishment of petroleum plant, or after coppice, other non food crops could be grown, such as energy crops. The risk –although not scientifically proven– of growing petroleum plant with food crops is the impact of toxicity on the products for later consumption. Whether toxins present in petroleum plant are excreted by the plant and then taken up by other (food) crop species remains to be seen.

Petroleum plants at the age of 6-12 months or more require lots of light and will generate too much shade to other crops affecting their growth.



Fig. 52-54. Fig. 52, Petroleum plant is grown in Africa as a hedge (Photo: M. W. Skinner, Grace 2008); **Fig. 53 and 54,** Living fences of petroleum plant in Ecuador (Photos: Ecoenergy B. G.).


Fig. 55 and 56. Fig. 55, Petroleum plant at Riohacha (La Guajira, Colombia) planted with ornamental plants; **Fig. 56,** ET (in the center) grown with *Jatropha curcas*. (Photos: Ecoenergy B. G.).

4.4.3 Plantations

Experimental plantations are reported in literature in India (Kumar 2009), Kenya (Duke 1983; Verstraete 1985), Zimbabwe (Grace 2008) and Japan (Kalita 2008). In Zimbabwe, plantations of petroleum plant have succeeded in some instances on the spoil mounds of arsenic mines (Grace 2008).

In Colombia Ecoenergy B. G. currently has possibly the only crop of ET for bioenergy, 0.6 ha. It is evaluating field experiments in La Guajira, Huila and Meta (Colombia). Now that sufficient planting material is available the planted area in Colombia and other countries is expected to expand (see **Fig. 57 and 58**). It is estimated that a plantation of one hectare of petroleum plant will produce enough electricity for approx. 11 households with an average consumption of 1000 kWh per household annually using a system that includes biodigesters, biogas engines and power generators (see also **section 5.1)**.

Fig. 57 and 58. Two examples of plantation of petroleum plant in Colombia. **Fig. 57,** Rozo (Valle del Cauca, Photo: Ecoenergy B. G.); **Fig. 58,** ET (indicated by arrows) planted mixed with grass at Puerto López (Meta, Colombia; Photo: Joaquin Umaña).

4.5 Cropping System Establishment

4.5.1 Plantation Establishment

To achieve sustainable farming of the petroleum plant it is advisable to establish plantations in regions where conditions are similar to the habitat where the plant naturally grow. We recommend to read also **Section 4.2 "Agro-Ecological Conditions"**.

4.5.2 Suitable Climate and Habitats

Petroleum plant grows over the widest distribution of all local *Euphorbiaceae* and thrives in semi-arid to semi-humid, moderate to warm climates. These range from tropical thorn to moist through subtropical thorn to moist forest life zones (Duke 1983).

Petroleum plant is very drought resistant and can survive in dry conditions during the whole summer, and tolerates annual precipitation of 250 to 500 mm, and annual average temperature of 21 to 28 °C (Duke 1983). Sometimes it has been observed that plants has been resistant to -2 °C (Corman 2001), but petroleum plant cannot tolerate freezing temperatures (Christman 2000) and the temperature cannot fall down below 7 °C (Corman 2001).

For optimal growth, petroleum plant needs bright light or sun (Corman 2001), around 1500mm of rainfall annually, evenly distributed throughout the year, and average mean temperatures of around 25°C. The plants increase their biomass at a still relatively high pace in semi-deserts (Maugh 1976).

It is commonly associated with human settlements. It naturalizes easily and is well represented in various habitats such as: moist forest, semi- deserts , brushwood, open woodland, grassland, shrub land, grassy hills, rocky outcrops and ridges, along river courses, bushes and open hot savanna vegetation (Voigt 2007, Duke 1983). It also withstands salt stress associated with coastal conditions.

Petroleum plant resists shaded conditions but under these conditions it grows very slow, developing thin stems.

4.5.3 Suitable Soil Types

Petroleum plant appears to grow on almost any soil type and this plant species can be grown in soils poor in fertility, although biomass production will then be limited. It is important that the soil is not prone to waterlogging. According to Melvin Calvin, *E. tirucalli* will grow in the same soils sugarcane will grow in, even without irrigation (Gogerty 1977). In the Eastern Plains in Colombia it has been observed that petroleum plants after two years of planting do not grow as fast as in other parts of Colombia. Possibly the strong wind, drought, extreme soil acidity and toxicity (aluminum over 80%), decrease the plants resistance after which termites affect their growth (personal communication Olivier Bouilland and Joaquin Umaña).

4.5.4 Unsuitable Areas

The development of petroleum plant should be avoided in nature reserves and areas susceptible to fires. Caution must be applied when planting this tree near any human settlement. It must not be in the near vicinity of wells or water collection sites as the tree contains toxic compounds that could contaminate the water (Barnes 2009).

4.5.5 Planting Areas of High Potential

In summary, petroleum plant has few requirements, and soil and growing conditions can vary widely. The plants are best established in open, full sun positions.

It is a tenacious plant that survives changes such as deforestation, drought and advancing deserts where no other plants can. In fact, it seems to thrive amid the devastation and is spreading in the hard red clay soil (Medical Research Products).

4.5.6 Preparation of the Soil and Planting Site

We suggest that the best way to prepare the soil is not to prepare it: no-till farming[41]. Only two conditions can change this concept: Soil should be prepared if: 1, surface irrigation is planned; 2, or in the presence of an impermeable layer which will affect the development of the roots of the petroleum plants. If irrigation by gravity is planned, it will be necessary to prepare furrows (see also **Section "Water management"**).

Before planting stem cuttings or transplanting rooted plantlets to the field, a plant hole (of about 30 cm x 30 cm x 30 cm) in the ground should be made using a hoe, soil auger, plough or other tool to open the soil sufficiently so that the plants can establish well (**Fig. 59-65**). Breaking an impermeable layer of soil is necessary when there is a risk that the plants will suffer from too much water caused by flooding of the land.

Fig. 66 demonstrates the root system of a three year old plant. Most plants will growth at a maximum depth of 40 cm only.

[41] No-till farming (sometimes called zero tillage or direct planting) is a way of growing crops from year to year without disturbing the soil through tillage. No-till is an emergent agricultural technique which can increase the amount of water in the soil and decrease erosion. It may also increase the amount and variety of life in and on the soil but may require increased herbicide usage.

A density of 1.600-20.000 plants per hectare is supposed to be optimal when grown as a fuel crop although no scientific data is available (Grace 2008, Orwa et al. 2009). The area occupied by a plant is presented in **Fig. 67**.

Fig. 59-61. Fig. 59, Hoe (Photos: Comercial Larach and Neofer); **Fig. 60,** pickaxe; **Fig. 61,** earth auger (Photo: Agriculture Post).

Fig. 62-65. Fig. 62-64, An ET field prepared by hand at Puerto Virgen (La Guajira, Colombia,), this region is characterized by its semi-desert conditions (Photo: Emilio López King, Nextfuel); **Fig. 65,** A field prepared using a tractor and a disk plow in Rozo (Valle del Cauca, Colombia) (Photos: Ecoenergy B. G.).

Fig. 67. From the measurements of 20 plants of petroleum plant in Rozo (Valle de Cauca, Colombia) it is estimated that the optimum tree plant density is 14,000 plants per hectare (Photo: Ecoenergy B. G.).

4.5.7 Direct Planting or Transplanting

See also Section 4.3 "Selection, Preparation of Planting Material and Reproduction Techniques"**.**

4.6 PLANTATION MANAGEMENT

ET is relatively easy to grow in different soils and under diverse conditions, and does not require special management practices. With a broad geographical distribution, there is no single method to grow petroleum plant. Productivity will be enhanced when water and nutrients are provided. Young plants grow relatively fast and will benefit from liquid fertilizers and well-composted, well-drained soils.

4.6.1 Water Management

Drought tolerance

Petroleum plant is highly drought tolerant and plants can also endure long periods without water. As ET survives in dry conditions, lack of water is not usually the most limiting factor. On the contrary, these plants can have problems caused by fungi by excess moisture.

Petroleum plant thrives in the driest atmospheres without artificial watering and feeding. Lack of water (rain, irrigation, ground water) does not allow growth of the plants. There is no indicator of water stress because leaves are frequently not present.

Irrigation

During rainy seasons the plants will be grown without irrigation and there is no need to water newly planted plants that have no roots.

We recommend to irrigate only when water is available at a low cost and when the soil is dry. To verify if the land is dry, you can insert a 50 cm long wooden stick in the soil. If the stick gets humid the plants still do not need water.

Watering can be thoroughly until the moisture soaks the soil well. In general, during cool weather, less water is required for irrigation. It is desirable to wet the ground directly, without wetting the stems or leaves. If the stems are wetted in sunshine, the drops can act as a magnifying glass and burn the stem tissue of the plants, therefore we recommend watering in the early morning or late afternoon.

The best water for irrigation is rain water, which can be collected in ponds and preserved before use. Water containing chlorine, salts and other substances that accumulate in the soil are not beneficial to the crop. To reduce the amount of chlorine in tap water (e.g. to irrigate a nursery) leave the water in a container for a few days to evaporate the chlorine. Calcareous irrigation water is not convenient. Water with a lower pH is preferred, although it should not be lower than 4. Water with a high salt content should not be used, because it accumulates in the plant tissues and causes great harm to the plants.

When water is supplied, growth of ET will start rapidly again. It is experience, rather than exact indications, that determines when irrigation should be done (**Fig. 68 and 69**).

Excess moisture

Succulent plants often have problems by excess moisture and therefore, it is better to have a shortage of water then excess and, as a general rule, leave to dry the land between irrigations. Too much water causes root rot which affects the whole plant. Bear in mind that the soil should have good drainage, so that the land will not be waterlogged. It is advisable to wet the soil directly, without wetting the stems. Too much moisture on the plants can cause spots, decay and affect the whole plant.

Salinity

Salinity stress studies were done on species closely related to ET (Kumar and Kumar, 1986). In the absence studies with ET the results below are believed to also be applicable to ET.

Salinity was applied in the form of irrigation water. Lower concentrations of salinity improved plant growth of candelilla or wax plant (*Euphorbia antisyphilitica,* a species similar to ET; Johari et al., 1990a) but higher concentrations inhibited further increase in growth. A slightly higher level of salinity impaired chlorophyll synthesis also. Sugars, however, did not increase in any saline irrigation.
Caper spurge or paper spurge (*Euphorbia lathyris*) could also tolerate lower salinity levels but its tolerance was lower than candelilla. In caper spurge salinity adversely affected root growth (Garg and Kumar, 1990). Devil's backbone (*Pedilanthus tithymaloides*) also exhibited increases in biomass and yield at lower salinity levels and higher concentrations adversely affected the plant. Its underground part could tolerate slightly higher salinity concentration (Rani et al., 1991).

Fig. 68 and 69. Irrigation of ET (Photos: Ecoenergy B. G.).

4.6.2 Nutrient Management

Although petroleum plant does not show any visible signs of nutrient deficiencies, its growth is reduced by it. Therefore it is recommended to provide nutrients to achieve that the crop produce high yields of biomass. No detailed studies on soil factors affecting yield are available but it is assumed to be favorable to fertilize a considerable amount during the growing seasons.

The decision to fertilize should be made only after there are indications that soil nutrient levels are (too) low. It is advised to test the soil fertility by commercially available tests for NPK levels.

Organic fertilizers

These nutrient sources are preferred over chemical fertilizers but there are not many options. Natural weed composting provides a fairly balanced amount of nutrients but not enough.

Another option is to recycle nutrients of ET and therefore it is likely to produce the crop with the effluent from biogas production using petroleum plant. More information about this system of electricity generation later in this publication, in **Section 5 on "Bioenergy Conversion"**. Biodigestion effluent provides a fairly balanced amount of nitrogen, phosphorus, and potassium. However, to prevent their decline, application of a liquid fertilizer with irrigation water will enhance production. It would be desirable to add a relative small amount of each nutrient in each irrigation during the growing season.

In caper spurge (*E. lathyrus*), application of manure increased height and fresh and dry weights of the plants in different degrees. Hexane and methanol extracts of the stems also increased due to the manure (Garg and Kumar, 1896, 1987a).

Chemical fertilizers

Application of nitrogen, phosphorous and potassium singly or in various combinations increased growth of petroleum plant. In general, a combination of nitrogen and phosphorus produced better growth of *E. tirucalli*, and a slight increase in potassium increased performance (Kumar and Kumar, 1986). When nitrogen (N), phosphorous (P) and potassium (K) were applied in different combinations like N-P, N-K, K-P and N-P-K, the last combination gave best results in the form of biomass, latex, sugars and chlorophyll yields in *E. lathyris* (Garg and Kumar, 1990; Johari and Kumar, 1993a) and *P. tithymaloides* (Rani and Kumar, 1994a). In *E. antisyphilitica,* however, NP combination gave best results, followed by NPK for biomass production.

An appropriate fertilizer for succulent plants in general is 20-20-20 (N-P-K). The fertilizer 25-15-15 (N-P-K), may also be favorable (Botanical-online SL. 1999). In the case of ET, because the plants have small leaves, a combination of nutrients with less nitrogen could be applied: 12.5 - 25 – 25 (N-P-K) or even a combination lower in nitrogen: 8-34 -32 (N-P-K).

Liquid fertilizer is ideal for succulents (or cacti), an example of a fertilizer composition is 300 ml per plant of nitrogen (4%), phosphorus pentoxide (6%), potassium oxide (9%), and micronutrients: iron, manganese, zinc, copper, dethylenediaminetetraacetic acid (EDTA) and boron (Gardenencasa).

It is suggested to use a fertilizer rich in potassium and phosphorus, but low in sulfur, because this chemical element can affect the development of succulent plants, making them too soft and full of water (Gardening.eu).

It can be concluded that until there are reported results of field trials, these preliminary results could be extrapolated to the petroleum plant.

Time and method of application

Most of the fertilizer needed should be applied in the initial preparation of the soil, because nutrients will be available for ET during some time.

It is recommended to fertilize at the beginning of each period of active growth of the plants which commonly is in the rainy season. A main problem to fertilize is that the crop is not easy to access when it is older than one or two years because there are many stems, and therefore nutrients must be applied after harvesting.

It is useful to apply the fertilizer in strips, close to the plants and cover the product by a thin layer of soil if possible (IPNI 2011). It is not recommended to fertilize in the full or direct sun although it will not be harmful for ET.

Nutrient management of mother plants

To accelerate growth, with the goal of having quickly mother plants, petroleum plant can be fertilized during the period of active growth -rainy seasons- every two weeks.

4.6.3 Application of growth regulators

Exogenous application of growth regulators has been reported in several horticultural crops, ornamental plants and sugarcane. Although there are no published results on the effect of growth regulators on the hydrocarbons of petroleum plant, we will refer to results obtained in other similar species. In an experiment with *E. antisyphilitica* maximum plant height was observed using GA_3, followed by CCC, NAA, 2, 4, 5-T and IAA treatment (see **Section 4 Abbreviations**). Foliar application of growth regulators resulted in increased production of fresh and dry weight (Johari et al. 1994b). IAA maximized the growth of *P. tithymaloldes* in terms of fresh and dry weight, and plant parts below ground. 2, 4, 5-T showed a minimum increase in plant growth, and some nodular structures were observed in the stem of the plants. Biocrude yield (hydrocarbons) was higher using IAA followed by 2, 4, 5-T, GA 3, CCC, NAA and the control (Garg and Kumar 1987b).

4.6.4 Weed Management

Careful weeding is necessary until plants are well established and a 'normal' crown with side branches develops. Weeding is necessary only when stem cuttings are not yet established, after 4-6 months, weeds are suppressed by ET because of lack of light from the crop.

When the plants are 50 cm tall it competes well with weeds. Herbicide applications are useful to lower the cost of weeding by hand. It requires about four applications between planting and the first harvest of the crop (**Fig. 70-73**). Field tests realized by Ecoenergy B. G. indicate a high tolerance of ET to glyphosate[42].

Fig. 70-73. Fig. 70, Weeding using a hoe; **Fig. 71 and 72,** Machete; **Fig. 73,** Herbicide application of ET in Rozo (Valle de Cauca, Colombia) (Photos: Ecoenergy B. G.).

[42] N-(phosphonomethyl)glycine (commercially known as round-up), is a broad-spectrum systemic herbicide used to kill weeds, especially annual broadleaf weeds and grasses.

4.6.5 Pest and Disease Management

Petroleum plant is not susceptible to most diseases and pests which affect most common crops. Duke (1983) publish that ET has "no natural enemies" (Duke 1983). During five years we observed many ET plants in different growing conditions and we never noticed any visible damage on the plants.

The photos in this chapter show various diseases and pests that are reported to affect petroleum plant. Although we have included in this document photos from some biotic problems observed in ET, we are presenting photos from diseases and pests observed in other crops. These diseases and pests are reported in literature to affect petroleum plant. Perhaps the presentation of these problems will be similar but it is observed that more research on plant diseases and pests in petroleum plant should be done.

Diseases

In India several diseases occur including stem rot caused by *Phoma sorghina* and necrotic spots by *Alternaria* sp., and *Nectria euphorbiana* were found on dead stem material directly into the field.

Parasitic plants

In Pakistan it is observed that petroleum plant can be a host of *Cuscuta* spp. (Grace 2008). It has to be noted that *Cuscuta* will not cause yield or crop losses because it is easily to remove the parasite by hand and, more important, *Cuscuta* does not grow well during dry conditions. Nonetheless care should be taken because *Cuscuta* can transmit phytoplasma (not reported yet in petroleum plant) which can reduce growth severely and there for *Cuscuta* should be removed as soon be detected.

Insects

Aphids, mealy bugs and grasshoppers feed on the plants, whereas (spider) mites (of subclass *Acari*) occur on leaves and young growth (Grace 2008).

Fig. 74, Development of the fungus *Diplodia* spp. on a recently cut stem of petroleum plant (preliminary identification), Photo: Ecoenergy B. G

Fig. 82-85. Fig. 82, Ello Sphinx - *Erinnyis ello,* preliminarily identified by Bernardo Arias (CIAT); **Fig. 83,** Alope Sphinx - *Erinnyis alope* of the family *Sphingidae* feeding on petroleum plant, preliminarily identified by Anthony Bellotti (CIAT); **Fig. 84,** Pupa and adult of Alope Sphinx. The pupal period should be about 15 days but this depends on several factors, mostly temperature (personal communication Anthony Bellotti, CIAT); **Fig. 85,** Adult (all Photos: Ecoenergy B. G).





Fig. 86-91. Fig. 86, Rose Grass Aphid (*Acrythosiphum (Metopolophium) dirhodum*). Photo: Jack Kelly Clark (University of California, 1998); **Fig. 87,** Adults and immatures of the coconut mealybug, *Nipaecoccus nipae* (Maskell). Photo: Lyle J. Buss (University of Florida); **Fig. 88 and 89,** Red locust (*Nomadacris septemfasciata*, preliminarily identified) feeding on the stems of petroleum plant**.** Photos: Ecoenergy B. G.; **Fig. 90,** Twospotted spider mites, *Tetranychus urticae* Koch. Photo**:** University of Florida**; Fig. 91,** Goat exploring petroleum plant, it is not sure if they structurally eat it (Photo: Ecoenergy B. G.).

Management Techniques

Several practices can be implemented by training field workers:

Selection of stem cuttings. By planting healthy stem cuttings, you can greatly reduce the spread and damage caused by pests and diseases. Healthy petroleum plants have green stems and branches, and minimal presence of pests and diseases. In selecting petroleum plants as sources of stem cuttings, you should avoid those infected with pests and diseases.

In general, petroleum plant do not show diseases or pests but the collection of plant propagation material from petroleum plant in areas where crops from the family *Euphorbiaceae* are affected by biotic stress should be avoided. Crops of this family can be hosts to pests and diseases that could affect ET. Well known crops of *Euphorbiaceae* are cassava (*Manihot esculenta* Crantz), rubber tree (*Hevea brasiliensis* Muell), castor bean (*Ricinus communis* L.) and poinsettia (*Euphorbia pulcherrima*).

Heat treatment of stem cuttings. Cuttings can be submersed in hot water at 49 °C during 49 minutes. This treatment reduces the presence of insects and several pathogens in the plant material. This method is effective in cassava (research realized by CIAT) and is expected to work for cuttings of petroleum plant (same plant family) as well.

Treatment of wounds. To prevent the growth of fungus the wounds of stems recently cut by a chain saw or machete can be treated by sulfur diluted in water and applied using a brush (**Fig. 92**).

Fig. 92. Recently harvested plant just before applying sulfur to the wounds (Photo: Ecoenergy B. G.).

Manual picking of locusts. If plantlets are recently planted in the field it is important to pick several days a week all locusts.

Fencing. Close planting, for example 30 cm between the plants, of the borders of the fields using petroleum plans should avoid the entrance of cows, goats and sheep. Distance between the plants can be wider using barbed wire fixed on the thick stems of petroleum plants.

Host resistance. No information is known or published.

Termites. Petroleum plants that have a strongly decreased defense as a result of stress (drought, lack of nutrients) can be attacked by Termites as was seen in drier areas in Colombia.

4.7 HARVESTING

4.7.1 Growth Rate

E. tirucalli grows vigorously once established and grows moderately fast, an average 0,4 cm per day under optimal conditions. ET growth is promoted by relatively high temperatures. The growth period of this plant is during the rainy seasons. In the dry period growth stops. Leaves are only present during the rainy season and flowering starts at the end of the dry season before new leaves are formed.

E. tirucalli is a rare example of a species in which the physiological mechanisms of Crassulacean acid metabolism (CAM[43]) in the stems are combined with C3 carbon fixation[44] in photosynthesis in the leaves. Other adaptations to drought include succulent stems and sunken stomata. Salt tolerance in ET is attributed to adaptations that limit the uptake of salt ions by the roots, and its storage in roots and stems.

No information is published concerning the growth rate of ET but Calvin observes that 5 cm cuttings increased one-thousand fold in one growing season, attaining more than 50 cm height in the first growing season (Calvin, 1980).

4.7.2 Harvest seasons

Thin and thick branches and stems of petroleum plant can be cut for bioenergy use throughout the whole year.

4.7.3 Harvesting methods

Main or thinner branches can be cut using a machete, ax, chainsaw, shredded, copped or mowed (**Fig. 93-97**). Calvin (1980) suggests tapping after reaching full size.

The harvest method must avoid that the person has contact with the latex of the plants because of its high degree of toxicity. This can be achieved by using goggles, gloves, long sleeves and a mask. The thicker the stems the harder is cutting the stalks by hand.
It is also advisable to harvest with a tractor with an enclosed cabin. **Fig. 17-19** show the latex. The designs of uniforms and other safety features to prevent poisoning from latex are described in **Section "Toxicity"**.

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[43] These plants fix carbon dioxide during the night, storing it as the four-carbon acid malate. The carbon dioxide is released during the day, where it is concentrated around the enzyme RuBisCO, increasing the efficiency of photosynthesis. The CAM pathway allows stomata to remain shut during the day, reducing evapotranspiration; therefore, it is especially common in plants adapted to arid conditions.
[44] This process converts carbon dioxide and ribulose bisphosphate (RuBP, a 5-carbon sugar) into 3-phosphoglycerate.

Fig. 93-97. Fig. 93 and 94, Harvest of ET using a chainsaw; **Fig. 95,** Thick stems harvested; **Fig. 96,** Recently harvested plants; **Fig. 97,** Thin (secondary stems) stems were cut and removed (Photos: Ecoenergy B. G.).

4.7.4 Potential Biomass Yields

Yield of ET stems for biofuel production varies greatly with density of planting, number of cuttings per year, annual rainfall and soil type. In Thailand annual yields varied between 150 MT fresh weight per hectare 20 MT fresh weight per hectare for high-density plots (10,000 plants per hectare) with 6 harvests, and 25.5 MT per hectare fresh weight for low density plots

(1,600 plants per hectare) with one harvest. A density of 10,000-20,000 plants is normal when grown as a fuel crop. When planted at a spacing of 1 m x 1 m it produced 120 MT per hectare fresh material and 14 MT per hectare dry matter after one year (88% moisture).

Philip Leakey, from Kenya, claims to be getting 400 MT biomass (fresh weight contains 85% moisture) per hectare in Kenyan areas with a rainfall of about 500 mm per year. Leakey perhaps meant that these were yields with a growing period of more than one year. Leakey claims to obtain 20 MT/ha charcoal from similar plantations. Such figures, if replicated, should be very encouraging to arid land inhabitants (Philip Leakey, September 28, 1981).

Measurements by Eco-energia showed dry matter contents of larger stems 26.2 %, leaves (16.4%), flowers (9.75%) and roots (41.2%). FACT measured the dry matter content of small young stem segments and found a DM content of around 11%.

4.7.5 Regrowth

ET coppices well at 20-30 cm height (Orwa et al. 2009), see **Fig. 98-100**. In biofuel plantations the plants can be cut at 20–30 cm above the ground. Under semi arid conditions the regrowth of petroleum plant is excellent. For energy purposes, Calvin suggests they be "cut near the ground and run through a crushing mill in much the same fashion as if done with sugarcane. In practice complete replanting is only necessary when crop production is no longer good, no longer productive or suffering from diseases or other problems. The plants themselves would regrow from the stumps, so replanting might be necessary only once every 20 years or so." (Maugh, 1976).

Fig. 98-100. Petroleum plant 30 days after harvest. Notes the regrowth of new stems and leaves (Photos: Ecoenergy B. G.).

4.7.6 Toxicity

Petroleum plant is an attractive indoor and outdoor ornamental tree (**Fig. 101-103**), nevertheless the plant contains caustic and irritant chemicals in the latex which cause reactions with the skin, mucous membranes, and the eyes (CBIF 2009). Toxic ingenol and 4-deoxyingenol are diterpenes that have been isolated from the latex of petroleum plant (Frohne and Pfander 1983; Fürstenberger and Hecker 1986).

Fig. 101-103. ET is commonly grown nearby and inside houses for ornamental purposes, but owners do not report any toxic effects (Photos: Ecoenergy B. G.).

Externally

Petroleum plant sap can cause minor chemical burns, making blisters or ulcers on skin and mucous membranes[45]. Severe burning and inflammation result after the latex comes into contact with the skin.

Cases of serious eye injuries have been reported. Petroleum plant latex causes keratoconjunctivitis if it gets into the eyes. The symptoms include immediate burning pain of the eyeball and eyelids, tearing, and photophobia. These symptoms are followed by 8-12 h of chemosis of the lids and conjunctiva, with blurred vision and increased pain. Erosion of the corneal epithelium, decreased visual acuity, and corneal oedema occur (Crowder and Sexton 1964). Temporary blindness has even been reported after untreated eye exposure.

Internally

Apparently, not well judged medicinal use of the latex of this plant has caused fatalities in East Africa (Fuller and McClintock 1986). Ingestion, even in small quantities and in diluted form, the plant or its sap (pure latex) causes burning and irritation of the mouth, throat, nausea, vomiting, diarrhea, haemorrhages, and stomach cramps and ulcers, accompanied by pain and perhaps diarrhea (Raintree Nutrition 2010).

Recommendations

All parts of petroleum plant excrete a milky sap when damaged or cut. Being nearby or in contact with this sap may cause many health problems (see above). The following recommendations are very important:

1. Children and pets may be harmed if they eat the plants or sap and there for it is recommended that family pets should not be allowed to ingest the plant (American Cancer Society 2008).
2. It is convenient to manipulate the plant with care using gloves and goggles that seal tightly the vision. A respiratory mask is optional (**Fig. 104-107**).
3. It is important to wash hands thoroughly with soap after handling plants.
4. Do not touch or rub your eyes without washing hands.
5. If a person feels irritation of eyes, mouth, and throat, consult a doctor immediately. In general it takes approximately five hours between the first contact with the latex and symptoms.

[45] The moist pink layer of cells that lines the eyes, nose, mouth, and other cavities in the body.




Fig. 104-107. Fig. 104, Training of members of a local Wayúu community in La Guajira, Colombia; **Fig. 105,** Double face mask and industrial Neoprene gloves (Photos: Emilio López King, Nextfuel); **Fig. 106 and 107,** Uniform and other safety elements for use during crop harvest (Photos: Ecoenergy B. G.).

4.7.7 Post-Harvest Handling and Storage

Maugh (1976) tested three different plant pretreatments: coarse chopped, ground and dried and ground material. Ecoenergy B. G. currently is comparing different methods to process plants.

Fig. 108-113. Fig. 108, Transport of several ET plants recently harvested; **Fig. 109 and 110,** Measurement of the weight of biomass produced by one plant (61 kgs); **Fig. 111,** Shredder; **Fig. 112,** Drying of ET in the sun; **Fig. 113,** ET ready to use for extraction of hydrocarbons (Photos: Ecoenergy B.G.).

5 BIOENERGY CONVERSION

Under optimal conditions, Euphorbia tirucalli (ET) produces between 200 and 500 MT of fresh biomass per hectare per year (22 – 55 MT of dry matter)(Van Damme 1999, Kumar 2000, Orwa 2009). Advantages are that only vegetative material is needed and there is no need to wait for flowering and fruit production; when cut back, the plant rapidly grows back by itself, and plantation can easily be established by vegetative propagation. The gross energy content of dry ET is 17,600 kJ/kg (Orwa *et al*. 2009).

There are also several unknowns, such as:

- The number of years that sustainable continuous yield is possible;
- Diseases that might develop (not found now in hedges of the plant);
- Number of times the plant can be coppiced before yield reduction will push for replanting.

A tentative first order comparison of the energy yields of ET is made with Jatropha curcas (JCL) and oil palm. For jatropha, a yield for semi-arid conditions is taken and electricity from oil and biogas from presscake is included. Oil palm is included as a reference to make clear that even compared to high yielding crops ET performs well. For oil palm, a low yield is taken (under semi humid conditions) with low extraction efficiency in small scale technology. For oil Palm, electricity output is higher when biogas from residues is included.

Table: Annual energy yields after conversion to electricity of Euphorbia tirucalli (Et) using conservative estimates, Jatropha curcas (JCL), Oil palm (considering small scale communal electrification technology)

	Et – oil	Et gasifier	Et – biogas	JCL (oil + biogas from presscake	Oil Palm (only oil taken)
yield/ ha/yr	2 MT oil extracted	37 MT Dry ET	37 MT dry ET	1,500 kg dry seeds /ha	1,950 liter/ha
electricity	6,600 kWh	3,700 kWh	11,880 kWh	2,330 kWh	5,850 kWh
level technology	very high[46]	high	low	Medium	medium
production cost	very high	medium	medium	High	medium

The first indication is that ET is attractive through a biogas conversion route. Secondly, it seems that under good conditions (precipitation, temperature and soils) it can surpass the energy yields of jatropha and even oil palm. Therefore, FACT Foundation decided to test the biogas yields that were demonstrated in a laboratory experiment by Sow et al. (1989).

5.1 Biogas

The entire plant contains latex, sugars, cellulose, which can all be converted to biogas through anaerobic digestion. Estimated production is 275 m3 of biogas (60% methane) per ton dry matter of ET. At a production of 30 MT/ha/year this results in 8,250 m3 biogas. In smaller

[46] Oil from latex is included to give an indication of yields but the technology is too complicated to apply in communal bio-energy systems

systems (biogas engine gensets) 1 m3 of biogas yields 1.44 kWh/m3. This results in a total output of 11,880 kWh per hectare per year.
Biogas production for dried pulverized Euphorbia tirucalli from Colombia was 293 liters/kg dry weight on average. The biogas production for 'fresh' Euphorbia tirucalli stems from Tanzania was 218 liters/kg dry weight on average (FACT biogas digestion experiments).

FACT and its partners are planning ET biogas projects in Colombia, Mali and Uganda.

5.2 Combustion

It is possible to burn dried ET directly. Data on this is not yet available. It is also possible to convert dried ET into green charcoal.

5.3 Gasification

Dried ET can be compressed into pellets or briquettes or be used directly for gasification. Experiments by Mr. John Loke in Colombia have shown that 200 liters (about 100kg) of dried and cut ET pieces produce about 10kWh, equivalent to energy yields of 100kWh per ton dry ET. At 30 ton DS/ ha/ year this would lead to 3,000 kWh. This can be a bit higher with more advanced gasification systems.

5.4 Hydrocarbons

The latex hydrocarbon is largely a C30 triterpenoid which, after cracking, yields high octane gasoline (Orwa *et al*. 2009). The costs for extraction are enormous and oil quality will be low; upgrading to fuel quality leads to considerable losses. Taking this into consideration, about 2,200 liters of fuel oil equivalent could be harvested per hectare per year requiring advanced chemical technology against very high costs. When used to generate electricity through a gasoline generator, this amount could generate 6,600 kWh (at 3 kWh/ liter) per ha per year.

5.5 Second generation ethanol

ET can be converted into sugars by pre-treatment and hydrolysis. The sugars can then be converted into ethanol. More information on the technical feasibility is needed.

5.6 Byproducts

Wood from larger ET trees could be used for timber, though the question is whether the wood is free from latex. Using wood from larger trees in not relevant for Jatropha plantations where the plants are cut before hardwood is being developed.

6 BIOENERGY APPLICATIONS

This chapter is still incomplete and will be elaborated when more data is obtained from pilot projects with ET.

6.1 Direct combustion

Biogas, ET briquettes or green charcoal produced from ET can be used for cooking and heating.

6.2 Electricity

With biogas a safe estimate for the production of biogas from ET is 225 liters/kg dry matter (based on various scientific studies). With a production of 50’000 kg dry matter/ha/year this leads to 11’251 m^3 biogas per year. At 1,44 kWh per m^3 biogas this results in 16’200 kWh. When using larger industrial biogas engines (bigger than 100kW) the efficiency goes up to 1,9 kWh / m^3 biogas and with a generally higher methane content of euphorbia biogas (60%) this could possibly be 2 kWh increasing the overall energy output.

6.3 Transport fuel

Hydrocarbons can replace gasoline. Biogas can be compressed and used as compressed natural gas (CNG) in adapted cars. These options require complicated and capital expensive technologies.

7 PROJECT IMPLEMENTATION

More details on the implementation of project based on *Euphorbia tirucalli* biomass will follow. It will include economic profitability and possible business models.

7.1 Sustainability

A plantation of *Euphorbia tirucalli* of which aboveground biomass is harvested annually is sustainable when the nutrients removed are returned to the field. The soil has a permanent cover by the crop and is held firmly together by the roots that are not disturbed. This increases the amount of available carbon in the soil over time and increase soil health.

In case of the production of biogas, the extraction of methane does not lead to nutrient losses since methane consists of nothing else than carbon and hydrogen molecules previously fixed from carbon dioxide and water in photosynthesis. When the digestate (effluent or residue after digestion) is returned to the same field from which the ET has been harvested several days before, the nutrients are almost all returned and the nutrient cycle is virtually closed.

Photo: Ecoenergy B. G.

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