Review of vegetative propagation of cacao (*Theobroma cacao* L.) by rooted cuttings. 1. Physiological considerations

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ABSTRACT

The paper reviews physiological factors that affect rooting of cocoa stem cuttings, including clonal differences, leaf area, physiological age, anatomical features, nutritional and biochemical factors which exert the strongest influence. Upper Amazon and Trinitario clones root better than Amelonado clones, the causes of the differences being mainly nutritional. Rooting does not normally occur in cuttings without leaves, because they are deprived of their photosynthetic function. Rooting decreases in general with increasing age of the tree. Cuttings from trees in healthy and luxuriant vegetative growth are, therefore, preferable. No major differences are observed in rooting between orthotropic and plagiotropic cuttings of cocoa. Information on the anatomical condition of cuttings in rooting performance is limited. However, a clear relationship is noted between the position of cutting on the stock plant and rooting performance; rooting potential increases from the apex to the base of the shoot. Single-node cuttings take longer time to root than multinode cuttings. The physiological condition of cacao cuttings changes with changing seasons, and this in turn affects their rooting performance. Cacao shoot is in optimal condition for rooting immediately after the flush has matured. The interaction of two or more physiological factors determines the degree of success in rooting .

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RÉSUMÉ

AMOAH, F. M.: *Propagation végétative de cacao* (Theobroma cacao *L.*) *par les boutures prenant des racines. 1. Les condidérations physiologiques.* Cet article fait une révision de facteurs physiologiques qui influencent la prise de racines des boutures de tige de cacao. Parmi les facteurs physiologiques influençant la propagation de cacao par les boutures de cacao, les différences du clonage, la surface foliaire, l'âge physiologique, les traits anatomiques, les facteurs nutritionnels et biochimiques exercent la plus forte influence. Les clones d'Upper Amazon et de Trinitario prennent les racines mieux que les clones d'Amelonado, les causes des différances étant nutritionnelles. Généralement la prise de racine ne se produit pas dans les boutures de tige privées de leur feuilles, les fonctions de la feuille pendant la prise de racines étant photosynthétiques implicites. La facilité de la prise de racine des boutures de cacao deminue en générale avec l'augmentation de l'âge de l'arbre. Les boutures des arbres en croissance végétative de bonne santé et luxuraint sont donc préférables. Il semble qu'il n'y a pas de différences majeures dans la prise de racines entre les boutures de cacao d'orthotropie et de plagiotropie. L'information sur la condition anatomique des boutures de cacao par rapport au résultat de la prise de racines est limitée dans la litérature. Toutefois il y a un rapport certain entre la position de la coupe sur le tronc de plante et le résultat de la prise de racine; avec le potentiel de la prise de racine augmentant du sommet au pied du tronc. Les boutures d'un seul nœud prennent de plus longue temps pour prendre les racines que les boutures de multinœud. La condition physiologique de boutures de cacao change avec le changement des saisons et ceci influence également leur résultat de la prise de racines. La pousse de cacao est en condition optimale pour la prise de racines sotôt après l'affleurement est mûr. L'interaction de deux ou plus des différents facteurs physiologiques détermine le degré de succès réalisé dans la prise de racine de boutures de cacao sous les différentes conditions de propagation.

Introduction

The problems involved in propagating cocoa from cuttings are different in some fundamental respects from those involved in propagating fruit trees and many ornamentals in the temperate regions (Evans, 1953). These differences arise primarily from the mode of growth of cacao trees, which like certain other tropical trees, shows a discontinuous growth in which the bud breaks, grows vigorously to produce the 'flushes' followed by a period of maturation of the flushes, with complete cessation of leaf growth for some weeks. The flushing process is later repeated.

Several workers have observed that the net assimilation rate of cacao is also comparatively low even under the most favourable conditions of growth (Goodall, 1950; Murray, 1951; Evans, 1953). The cacao plant does not accumulate large quantities of carbohydrates because its reserves are used periodically in producing new growth flushes. Evans (1951) observed that the reserve of nutrients is only enough to maintain a cutting for a few days (5 to 8 days) after which it starves and dies. It is essential, therefore, that the cutting be allowed to carry on normal photosynthesis during rooting, and the photosynthetic product must be enough in quantity to cater for respiratory requirements and provide raw materials required for the initiation and growth of roots (Evans, 1953).

Plants from cuttings have been observed to be more productive, attaining their highest yield at an earlier age than seedlings; because they are less vulnerable to seasonal climatic differences and, therefore, produce well in adverse seasons (Jolly, 1956). It is, therefore, necessary that techniques are developed to intensify the production of cocoa planting materials by rooted cuttings. Good clones do better as cuttings while poor ones may perform better when budded, presumably because of differing root systems (Cope, 1953). Good clones have been observed to produce better root systems than poor clones.

Propagation by rooted cuttings requires high technical expertise for an acceptable rooting percentage as well as special facilities to produce rooted cuttings. This makes it difficult for commercial farmers to adopt the technique on a large scale. Several workers have attempted to simplify the technique of rooting cuttings which could be applied widely by commercial farmers (Murray & Bridge, 1956), but have had limited progress so far. Several factors, either in isolation or in combination with many, affect the degree of success in propagating cacao by rooted cuttings. These factors may be broadly categorized under physiological, environmental, and technical considerations.

Work on vegetative propagation of cacao seems to be dwindling in recent times because many cocoa-producing countries resort to using seedling materials which are cheaper to produce. Hence, publications on recent work on vegetative propagation of cacao is limited.

This review aims at assembling information on physiological factors that affect rooting in cocoa stem cuttings to develop a package that will be beneficial to researchers who would raise cocoa planting materials by stem cuttings for research programmes and supply to farmers.

Clonal differences

Most cacao cultivars have been classified as either 'difficult', 'moderate', or 'easy' to root because of the wide range of variability they show in the degree of success in their propagation as cuttings (Jorge & Gustavo, 1981; Evans, 1953; Hall, 1963; Toxopeus, 1970; Ramadasan, 1979). The problem of genetic erosion in desirable cocoa clones, due to difficulty in propagating these materials vegetatively, requires an intensive study to explain the problem.

Hall (1963) examined 30 cocoa clones for production of cuttings and for their rooting potential. He observed that Upper Amazon and Trinitario clones produced cuttings in large quantities and rooted better than Amelonado cocoa. A high correlation coefficient (0.75) was established between rooting response and the cutting production of each clone. This suggests that cocoa clones with vigorous growth should be preferred for vegetative propagation by rooted cuttings than slow-growing clones. Evans (1953) stated that such differences in rooting between cacao clones are minimal when cuttings are treated with root-inducing hormones. Evans (1953) established that the causes of the differences between clones in rooting were mainly nutritional. Introducing sucrose and various amino acids into leafy cuttings and treating with optimal dosages of root-inducing substances (between 4000 and 8000 ppm) converted the difficult-rooting clones into easy-rooting ones. The author further observed that many difficult-rooting clones were susceptible to nutritional disorders in the field. Adding small amounts of vitamin B_1 and iron and manganese salts (50-500 ppm) improved the rooting of such cuttings.

Toxopeus (1970), in studies on seasonal trend of rooting success of cacao in Nigeria, observed a clear effect of seasonal influence on rooting in any particular year. He observed that rooting ability in the dry season of most Upper Amazon clones was relatively good (39-60%), whereas that of many Amelonado or Trinitario clones was poor (0-20%). In the Trinitario clones, rooting ability in the wet season was not consistent; however, there was a general trend toward a decline in rooting in the rainy season, particularly from May to June. The major decline from May to June is thought to be a genuine gap that has some bearing on climatic factors which affect flushing. In general, the easier rooting is in the dry season, the better and more consistent it will be in the wet season; because in most clones (except the Trinitarios) rooting ability decreases with increasing moisture stress. Rooting success in the dry season may also indicate the degree to which an inherently high-yielding clone will be able to express its yield potential within the first 10 years of its life in a plantation (Toxopeus, 1970).

Ramadasan (1979)also observed under Malaysian conditions that clonal variation is strongly evident in hardening and survival of rooted cuttings which are also strongly related to clonal vigour. Hartman & Kester (1983) have also observed in the propagation of other crop species that poor rooting in certain clones may be due to low nutrient reserves or lack of rooting co-factors or both. This suggests that in selecting cuttings for rooting, plants in luxuriant growth with high reserves of nutrients and rooting co-factors, such as indigenous hormones, should be preferred because cuttings from such plants give better rooting.

Effect of leaf

Evans (1953) established that rooting did not normally occur in cacao stem cuttings deprived of their leaves. After being treated with synthetic root-inducing hormone and the necessary precautions taken to avoid fungal and bacterial infection, such leafless cuttings still failed to root. The function of the leaf during rooting is to provide the cuttings with carbohydrates and, to a lesser extent, with nitrogen compounds. Ramadasan (1979) also observed that if enough planting material is available, multi-leaf cuttings may be used to advantage, with better rooting and more rapid growth and development. However, if the temperature is high, defoliation may set in so that no advantage of increased leaf area is derived.

Overbeck *et al.* (1946) and Copper (1938) also observed in the rooting of other plant species that leaves exert a strong stimulating influence on root initiation. Bowman (1950) reported that cuttings with more leaves showed no superiority over three-leaf cuttings. Amoah (1986) observed that the total leaf area per cutting required for optimum rooting depends on the length of the cutting, while single-node cuttings of about 4 cm stem position will root easily when the total leaf area is between 80 and 100 cm^2. Multinode cuttings of about 15 cm length will need a total leaf area of about 300 cm^2. The use of single-leaf cuttings, though attains a high percentage of rooting success, entails a retardation of some 2 or 3 months in subsequent development.

Ramadasan (1979) stated that if materials are inadequate, practical considerations dictate that more cuttings would be available only if fewer leaves per cutting are permitted. This will also reduce the cost of managing the nursery. For general propagation, cuttings with two to four trimmed leaves seem to be ideal (Evans, 1951; Murray, 1954; Are & Gwynne-Jones, 1974; Ramadasan, 1979). Single-leaf cuttings should only be resorted to in severe shortage of propagation material, or an advantage in timing nursery operations and field planting. Leaf trimming enables a higher density of cuttings within the propagator, and minimises self-shading of leaves in the same cutting or mutual shading between adjacent cuttings. However, because the primary role of the leaf is photosynthetic, care should be taken to avoid reducing the leaf area below a minimal level. A correlation exists between the amount of light intercepted by a plant and its dry matter production, and leaf area plays an important role in light interception.

However, Evans (1953) noted that the extent to which leaf area of the cutting could be reduced without inhibiting rooting was influenced by the diameter of stem with which the given leaf area was associated. For example, a third or less the leaf area of an average leaf was adequate to produce roots when the associated stem portion was about 2.5 cm, but the same leaf area would be inadequate if the stem portion was 30 cm in length. This observation suggests that rooting in cacao stem cuttings was dependent on the drain on photosynthates by the respiratory needs of the stem tissue. The standard practice in propagating cuttings seems to be the use of multi-leaf cuttings (Cheesman & Spencer, 1936; Nichols, 1958; Gnanaratnum, 1964). However, McKelvie (1957) used two-leaf cuttings while Stahel (1947) used single-leaf cuttings.

Bowman (1950) has observed that without water stress, half leaves were as effective as whole leaves in promoting rooting. However, when leaves were reduced to less than half size, rooting was retarded. The function of the leaf is almost entirely photosynthetic; however, for leafy cuttings, optimal conditions for photosynthesis should be provided during the rooting period. These observations suggest that for optimum rooting, cuttings should be provided with leaves whilst avoiding mutual or self-shading or both. Environmental conditions should also be favourable for normal photosynthesis to take place to provide the cuttings with nutrients required for rooting.

Physiological age of cutting

The best material for rooting in cacao has been observed to be from trees in healthy and luxuriant vegetative growth (Evans, 1953). Successful rooting can only be ensured if the materials to be used are carefully selected. Materials from juvenile trees are essential for rooting. Rooting decreases in general with increasing age of the tree, unless the juvenile characters are restored by a suitable pruning technique. The leaves of the flush to be rooted should be green and mature, and the stem should still be green but just about to turn brown (Evans, 1953). But Bowman (1950) reported that a healthy shoot of cacao with healthy, firmly attached leaves can be rooted when treated appropriately. Pyke (1932) reported successful rooting of softwood cuttings. Ramadasan (1979) also observed that softwood and semi-hardwood cuttings performed better than hardwood cuttings. Hardy (1960) preferred the wood to be a little older.

These observations indicate that physiological age of cuttings alone may not be a suitable indicator for use in selecting materials for rooting. The interaction of other factors, including condition of the leaves and clonal variation, should be considered. Pyke (1932) has shown that cacao has exacting requirements about the maturity of wood required for successful rooting. Shoots actively producing flushes of new growth were unsuitable because they frequently rotted and died back. Fully mature shoots carry senile leaves which readily abscise. The best stage for rooting was immediately after a flush of growth, when the leaves were fully expanded but still quite young. Hardy (1960) stated that stems carrying flowers should not be used, because at this stage, the wood is too old to root well.

Ramadasan (1979) compared rooting in fan cuttings (plagiotropic shoots) with that in chupons (orthotropic shoots) and reported that both materials performed equally, and that the choice of one over the other depended on the abundant availability of the type of material.

Other workers have reported success in rooting with fan and chupon materials (Keeping, 1950; Evans, 1953). However, Urquhart (1961) remarked that, in general, cuttings from fan shoots were used for propagation owing to the limited availability of chupon material. Archibald (1952) also argued that with the use of short cuttings, chupon cuttings root quicker and more evenly than fan cuttings, and also show more rapid bud-burst and shoot growth. However, with the use of long-stem cuttings, chupon material takes far longer and is more difficult to root. From the evidence available, it may be imperative to suggest that more work is required to fully explain the effect of physiological age and wood type on rooting in cacao.

Anatomy, stem size, and position on stock plant

Evidence of anatomical effects on the rooting of cuttings of many plant species have been well documented (Beakbane, 1961; Girouand, 1967a, b; Edward & Thomas, 1980; White & Lovell, 1984a,b). Edward & Thomas (1980) reported that the presence or absence of sclerenchyma cells may determine the ease or difficulty of rooting ability in most plant species. Brook & Guard (1952) studied the vegetative anatomy of cacao and stated that chupon and fan wood have fundamentally the same anatomy. This may imply that any anatomical effect on rooting in cacao will be common in fan and chupon cuttings. Anatomical differences do not only cause physical barriers to rooting, but may also influence physiological effects such as limiting gas exchange, hampering cell differentiation, or preventing the availability of substrate to the enzyme in the formation of rooting factors (Haising, 1974). Little information has been published on the anatomical features in the tissues of cacao cuttings at the site where root primordial are differentiated. However, Brook & Guard (1952) reported that evidence of preformed roots is lacking in stem sections of cacao.

Most researchers working on cacao propagation have observed differences in rooting performance with position of the cutting on the stock, but have not correlated this with anatomical features at the point rooting occurs. Evans (1953) observed that in young trees, the position of shoots on the tree from which cuttings are taken is of little importance. In older trees, however, cuttings taken from the base of the tree root easily. As the tree ages, the cuttings taken from it root with difficulty and are less vigorous (Ramadasan, 1979). Though this phenomenon may be due to such factors as the biochemical and nutritional state of the materials, changes in the anatomical features of the trees from juvenile to mature state could possibly be involved. In a single suitable fan shoot, it was reported that a rooting potential gradient increased from the apex to the base of the shoot (Anon., 1950). The anatomical features of cuttings taken from various nodal positions on a single shoot may also relate to the stem thickness and their subsequent effect on rooting. Cuttings with smaller stem and larger leaf area have been noted to root easily, and survival rate of rooted cuttings is high during weaning (Amoah, 1986; Ramadason, 1979).

The size of cutting selected for rooting depends mostly on the availability of materials and the time of field planting. Evans (1951) observed that single-node cuttings took a longer time to root than multinode cuttings, and that the growth rate of plants raised from single-node cuttings was retarded. This may imply that they took a longer time to reach planting out stage. Ramadasan (1979) also noted that cuttings with a minimal length of stem tissue showed poorer rooting and survival. These observations underline the many technical difficulties involved in raising young plants from single-node cuttings. It may be reasonable to suggest that the optimal amount of stem tissue on a cutting should be a compromise between storage requirements and energy expended in maintaining respiration. The standard method of raising cacao from rooted cuttings has been the use of multinode cuttings of about 15 cm in length of stem tissue or more.

Nutritional and biochemical factors

The nutritional and biochemical factors involved in rooting cacao include seasonal effect, endogenous growth hormones, co-factors, inhibitors, and the nutrition of stock plants. Hartman & Kester (1983) stated that, in general, the poor rooting of materials of some plant species may not be due solely to a limited hormone supply, but could also be due to factors such as availability of carbohydrate reserves, nitrogenous substances and rooting co-factors, or high concentration of inhibitors. The differences in the rooting ability of cacao clones have been observed to correlate with differences in their nutritional status (Evans, 1953), and also with varying levels of endogenous hormones in the various clones. It is necessary that cuttings taken from slow-growing clones be treated with optimal concentration of growth substances to promote rooting. Evans (1951) observed that when leafy cuttings were injected with solution containing 3 per cent sucrose, 200 ppm arginine, 1 ppm vitamin B, 100 ppm $FeSO_4$ and 100 ppm $MnSO_4$ and treated basally with hormones, rooting was improved considerably, and clonal differences were no longer observed. Even the difficult-rooting clones rooted readily in 3 to 4 weeks.

The hypothesis that the function of the leaf during rooting is basically photosynthetic is deduced from the fact that breakdown and abscission of leaves, often associated with poor rooting percentage, is due to the nutritional status of the leaves at the time cuttings were taken (Evans, 1953). Several physiological or environmental factors were found to be responsible for such unfavourable nutrition. The most important were unfavourable balance of nutrients within the cuttings as a result of mineral deficiencies, and overexposure or underexposure to light.

Season of propagation

The internal condition of cuttings has been observed to change with the changing seasons as well as rooting response. Cacao clones have different patterns of rooting success of cuttings during a year (Toxopeus,1970). This could be linked to environmental changes in the propagation area as well as to internal condition of the cuttings. Ramadasan (1979) reported a clear seasonal effect on shoot production and rooting. He observed that good rooting is associated with the rainy months. Because plants will be in luxuriant growth with high rates of photosynthesis and nutrient uptake, cuttings taken during the rainy periods tend to root well. During active cherelle production, a considerable amount of dry matter is diverted toward fruit development. This influences the amount of food reserves in the shoots and, hence, their rooting ability. It would, therefore, seem that success is maximum only in wet weather when the source plants are in a state of vigorous vegetative growth and external environmental factors, particularly temperature within the propagators, are more readily manipulated. It is also possible that at the beginning of the dry season, major and rapid changes occur in the metabolism of shoots, particularly in hormone balance such that even hardwood cuttings root well (Ramadasan, 1979).

During the dry season, the situation may have stabilized and rooting ability in cuttings decreases. While softwood and semi-hardwood cuttings survived better during the dry season, rooting behaviour was not significantly different among the type of materials; also, hormone treatment did not seem to be beneficial (Ramadasan 1979). Evans (1953) observed that a shoot is in optimal condition for rooting immediately after the flush has matured; that is, when the leaves are fully hardened and the wood is green but hard, or is changing to light-brown. In practice, the leaves on such shoots become full-green when the above stage of development has been reached, and only when light intensity and supply of mineral nutrients are adequate.

Evans (1953) observed in Trinidad that during the wet months of the year under heavy rainfall, the rate of nitrification is low and the rate of leaching is high so that nitrogen uptake by the young flushes formed at this time is low enough to result in mild to acute symptoms of nitrogen deficiency. The rate of iron uptake is also greatly reduced under conditions of defective soil aeration. Other elements such as magnesium, manganese and rarely copper and zinc may become deficient, and success in rooting cuttings is greatly reduced. These observations suggest that probably the best time to take cuttings from field- grown plants is at the beginning of the rainy season. During this period, the nitrate-nitrogen accumulation which occurs during the dry season becomes readily available; and increased uptake of iron and other microelements owing to improved aeration results in shoots of healthy vigorous growth which root readily. It may be concluded that stock plant nutrition, as influenced by seasonal changes, is of primary importance in the successful rooting of cuttings. Cuttings selected for rooting should, therefore, be taken when the mother plant is in luxuriant growth with high accumulation of carbohydrates and minerals.

Conclusion

Physiological factors strongly influence rooting in cacao cuttings. Notable among these factors are clonal differences, leaf area, physiological age, anatomical features, nutritional and biochemical features, and the season of propagation. A clonal variation exists in rooting potential in cacao. Vigorous clones normally give good rooting response compared to less vigorous ones. Rooting does not normally occur in cacao cuttings deprived of their leaves. Successful rooting can only be ensured if the materials to be rooted are carefully selected. Rooting decreases in general with increasing age of the tree. The anatomy of chupon and fan wood is fundamentally the same. Evidence of preformed roots is lacking in stem sections of cacao. The cacao plant does not accumulate large reserves of carbohydrates because its reserves are used periodically in producing new growth flushes. Hence, conditions should be provided to facilitate normal photosynthesis during rooting to cater for respiratory requirements and provide raw materials for the initiation and growth of roots.

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