

Optimal utilization of cocoa germplasm - seedling establishment

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Although plant breeders may develop germplasm of impeccable potential, its optimal use in the field will depend upon efficient propagation, transplantation and establishment of stock material on plantation sites. Frequent watering of stock in nurseries is expensive, in both labour and water, and difficult in remote holding stations where water is very scarce. Even when first class stock is planted, seedlings may not survive because of water stress. Can water-binding polymers added to compost reduce the cost of raising stock and improve the establishment of valuable germplasm in the field?

A project at Liverpool University, UK., (funded by the Ghana Cocoa Growing Research Association Ltd.) is evaluating the potential of such polymers for:

- i. raising uniform and vigorous nursery stock;**
- ii. improving the establishment of seedlings in the field;**
- iii. improving the reliability of bare-root transplantation; and**
- iv. carrying, and slowly releasing, fertilizer, pesticidal and fungicidal agents to maximize efficiency of use and minimize environmental impairment.**

To underpin the programme, study of the basic physiology of water use by seedlings and their response to water stress is also being carried out.

Work to date has shown that growth of the root system is much enhanced by the polymer P4, indeed roots appear to "seek out" and grow through polymer granules. Polymer-bound water is utilized by plants. In relation to the aims above:

- i. Healthy and uniform seedling growth is maintained with less frequent watering, and seedlings transplanted within a nursery environment survive drought much better with polymer-amended compost.**
- ii. In a 1992 dry season trial in Trinidad, polymer use did not improve seedling establishment in the field, but the drought in this instance was very severe.**
- iii. Establishment of bare-root transplants is improved when seedlings are raised with polymer, but not when only used as a "root dip" on transplanting.**
- iv. Polymer can absorb small quantities of fertilizer ions, some of which are readily released into the soil. Work relating to pesticides and fungicides is underway.**

Introduction

Nursery grown cocoa seedlings, normally four to seven months old, are generally used to establish plantations and replace mature stock lost through disease, etc. Successful seedling establishment in the field requires favourable levels of nutrients and water. Although planting can often be carried out in a "rainy season", rainfall can still be unpredictable and transplanted seedlings, especially in Ghana in recent years, can experience harmful drought periods both within the rainy season and as a result of an extended dry season.

Water stress in transplanted seedlings can be alleviated by irrigation, mulching and the use of antitranspirants, etc., but these treatments are costly. Renewed attention has been focused on the potential of synthetic superabsorbent polymers, typically absorbing several hundred times their own weight of water, to act as reservoirs of soil water. Such polymers have been used commercially to aid establishment of cotton and tobacco crops in the USA. Presently polymers are relatively expensive, but prices are falling and with the possibility of production in the Third World, could fall much further, making their use more cost effective. The mode of use does not require any high technology or specially trained labour. Polymer is either mixed into compost for use in raising seedlings in the nursery or into the soil around the planting hole to support establishment in the field.

The criteria for selecting a particular polymer type include its cost, water holding capacity (WHC) and stability in the soil. The WHC of polymers is reduced by various ions, so that polymer salt-buffering ability also needs to be considered in its selection (Johnson, 1984; Bowman *et al.*, 1990). Equally important is the potential at which water is retained in the polymer (Baasiri *et al.*, 1986).

Improvements in the physical characteristics of soils following the incorporation of polymers have often been reported (e.g. Azzam, 1983). A recent experimental development is the incorporation of additional biologically active organic and inorganic compounds (M.S. Johnson, *personal comm.*) into polymers which can exert influences, in addition to water supply, over plant growth.

The paper reports initial work on a project evaluating several aspects of the potential of polymers to improve cocoa seedling development in the nursery and establishment in the field. These include:

- i. raising uniform and vigorous nursery stock;
- ii. improving the establishment of seedlings in the field;
- iii. improving the reliability of bare-root transplantation; and
- iv. carrying, and slowly releasing, fertilizer, pesticidal and fungicidal agents to maximize efficiency of their use and minimize environmental impairment.

Work to date has concentrated on aspects of i. to iii. Basic physiology of water use by cocoa seedlings and their drought tolerance characteristics has also been carried out to underpin the polymer evaluation. Data will be reported later. The approach taken has been that polymers would be likely to increase the interval between watering periods in the nursery and reduce irrigation demands in the field should there be dry spells soon after planting out.

The polymer chosen (after preliminary trials) for detailed study is known commercially as "P4". It is polyacrylamide with a good WHC (binds approximately 400 times its own dry weight); water release pattern, and proven stability in the field at the high temperatures typical of cocoa plantations. P4 is marketed by Agricultural Polymers Ltd., Gloucester, UK.

Work reported here concerns the effect of P4 on:

- i. seedling growth and survival under reduced watering frequency (Experiment 1), and
- ii. establishment of seedlings raised with or without P4 and transplantation into soil with or without further P4 in both nursery and field sites and the bare-root transplantation technique - initial experiment (Experiment 2).

The effects of separate mulching and its interaction with P4 use was also evaluated.

Materials and methods

Experiment 1

Two month old Amelonado cocoa seedlings grown in 11.5 cm diameter pots containing 800 cm³ of compost were transplanted into 28 cm diameter pots containing 4 dm³ additional John Innes No. 1 (JI-1) compost $\pm$ P4 with all mixtures at field capacity for water. The recommended agricultural dose of P4 is approximately 1 g l⁻¹ of compost (Agricultural Polymers Ltd.), however early trials showed this to be insufficient for cocoa seedlings. The three levels of P4 addition used were therefore 3, 4 and 5 g l⁻¹ of compost to give 12, 16 and 20 g per plant respectively. Control plants received only JI-1. Each treatment was replicated six times and pots of three of each set of six were covered with an aluminium foil to provide mulch simulations for each treatment. The full experimental set was as follows:

T1a	=	No P4, no(-) mulch	:	T1b	=	No P4, + mulch
T2a	=	12g P4, - mulch	:	T2b	=	12g P4, + mulch
T3a	=	16g P4, - mulch	:	T3b	=	16g P4, + mulch
T4a	=	20g P4, - mulch	:	T4b	=	20g P4, + mulch

Gypsum resistance blocks (Eijkelkamp, The Netherlands) were incorporated into pots to allow daily changes in compost moisture to be monitored with a soil moisture meter (Eijkelkamp, The Netherlands).

Plants were watered daily to field capacity for 30 days to allow seedlings to establish themselves, after which watering was withheld. Water loss from all pots was determined by daily weighing at the same time of day on each occasion.

Plants were positioned randomly and maintained in a growth room with temperature 25°C $\pm$ 1°C, RH 55 $\pm$ 5% and a light intensity of 260 μ mol m⁻² s⁻¹ PAR.

Droughting continued for 52 days though some plants in some treatments wilted severely and shed leaves before this point. To assess root development, plants not mulched were re-watered to field capacity and then compost carefully washed from the roots before qualitative assessment of root development. Pots which had been mulched were oven-dried after removal of the shoot at the compost surface. From the dry weights of each treatment, and the wet weights of the pots at the start of the experiment, it was possible to calculate the water content of the pots at any given time. Leaf areas of plants at harvest were estimated from measurements of leaf length and width using the relationship of Machado (1986).

Preliminary experiments showed that cocoa leaves wilted when readings on the soil moisture meter had declined from 96 (= field capacity) to around 5 (= 8% field capacity). This value is therefore used as the arbitrary wilting point for all plants.

Experiment 2 - transplanting and bare-root experiment

Amelonado seedlings (cultivar M8) were raised from seed in the nursery of the Cocoa Research Unit (CRU), The University of the West Indies, Trinidad, in a range of P4 amended composts with 3 litres compost per plant (root-ball). When seven months old, seedlings were transplanted either into 13 litre buckets or into a field site on the CRU experimental station at La Reunion, Trinidad. Mulch treatments were incorporated into both sub-experiments using the plastic bucket lids (33 cm diameter) fitted centrally around plants.

Transplanted seedlings (nursery and field) were pre-grouped according to plant size and stage of development of the youngest leaf flush into four blocks, with four replicates per treatment. In both cases, seedlings were transplanted with the root-balls intact. Polymer granules were thoroughly mixed with the soil into which seedlings were transplanted in buckets and mixtures brought daily to field capacity for four days before transplanting. At the field sites, P4, when added, was used at a rate of 40 g per planting hole of approximately 30 cm x 30 cm x 27 cm (approx. equal in volume to the 13 litre buckets).

Seedlings in buckets (nursery) were droughted (zero water) for 45 days, by which time plants in some treatments had shown signs of severe water stress. Plants were then watered once to field capacity and a second drought regime imposed for 22 days, at which time watering again took place. There was no further watering up to plant harvest.

Field seedlings were thoroughly irrigated six days after transplanting to ensure complete hydration of the polymer and then left unwatered. Here there were six replicates per treatment grouped into six blocks. The field experiment ran for 125 days from 19 February to 23 July 1992. Rainfall for the first 74 days during the period (before the end of the dry season) was approximately 80 mm, representing an acute dry season.

At the end of the experiments, plants were harvested and fresh and dry weights determined for leaves, stems and roots.

Plant development was monitored - leaf number and sizes, flush numbers and flushing period - throughout the experimental periods, but only data for final plant size are presented here.

Summary of treatments; notation is identical for nursery and field experiments

Treatment	Nursery Medium (root ball)	Transplanting regime
T1 T2	No P4, no mulch No P4, no mulch	No P4, no mulch No P4, mulch
T3 T4	No P4, no mulch No P4, no mulch	40g P4, no mulch 40g P4, mulch
T5 T6	4.5g P4, no mulch 4.5g P4, no mulch	40g P4, no mulch 40g P4, mulch
T7 T8	9g P4, no mulch 9g P4, no mulch	40g P4, no mulch 40g P4, mulch
T9 T10	15g P4, no mulch 15g P4, no mulch	No P4, no mulch No P4, mulch

Experiment 1

Figure 1 shows the total change in leaf area (reflecting growth) over the drought period of the experiment. Mulching slightly increased leaf growth, but P4 had no significant effect on this parameter at any applied level.

Figure 1 Treatment effect on mean change in leaf area

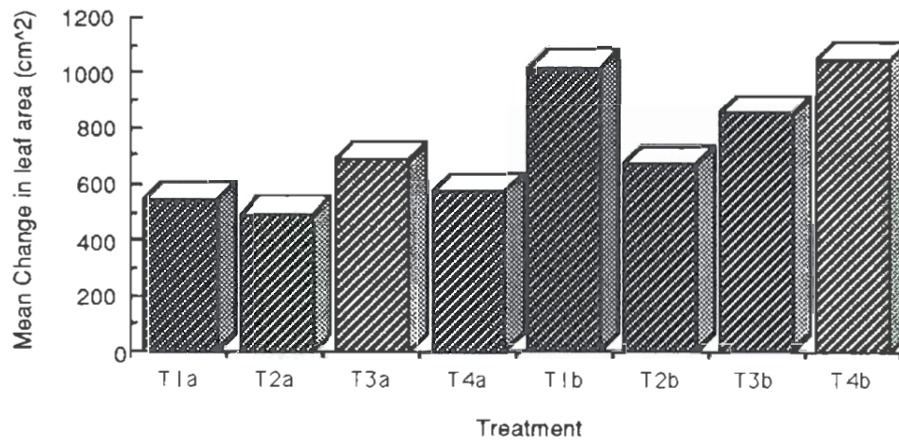
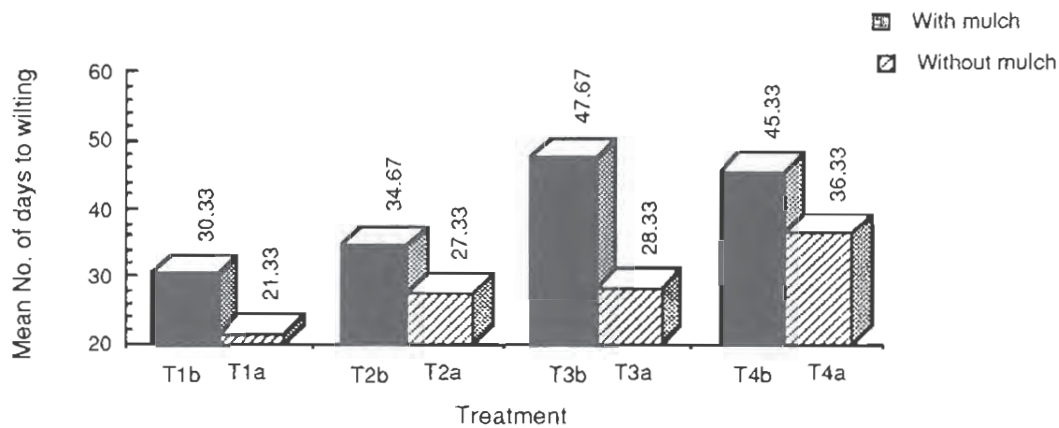


Figure 2 shows clearly that P4 does extend the period before leaf wilting occurs and that extension increases with higher P4 levels. Results with mulch show exactly the same pattern, but the length of the extension period is greater at all polymer levels.

Figure 2 Treatment effect on number of days to moisture meter reading = 5



For the **bare-root transplantation experiment**, seedlings were grown in the nursery as described earlier in either compost alone or compost amended with 3 g l^{-1} P4 (= 9 g per root ball). Before transplanting into large containers, seedlings were: (i) removed from pots and material around roots removed in the standard way for preparing bare-root stock, then (ii) sub-sets dipped or not dipped in powdered, hydrated P4 and (iii) all exposed to air for two hours. (There were thus four treatments in total: with and without P4 before transplanting and each with or without a P4 root-dip at the bare-root stage.) Seedlings were then planted into big containers and maintained in the nursery with weekly watering for 14 days.

Results and discussion

The extension period does vary between plants within treatments reflecting the differences in leaf area of individual plants, but overall the P4 effect is very clear.

Figure 3 shows the effects of P4 and mulch on the rate and total amount of water loss from selected treatments to the point when plants wilted. Loss is of course due to a combination of transpiration and evaporation from the compost surface. As expected, the rate of loss is higher without mulch (T1a, T2a and T4a compared with T1b and T4b). The presence of P4 has no effect on rate of loss. The end of each plot-line (days) shows when plants wilted, and the cumulative water loss at this point (g), the water available in each treatment to the wilt point. The retention capacity of P4 is well shown with 2500 g available at high levels (T4a and T4b) compared with only 1800 g in control (T1a and T1b). Accordingly, P4 very significantly extends seedling survival time to the wilting point; 21 days for no P4 control (T1a), 27 days for low P4 (T2a) and 36 days for high P4 (T4a). High polymer without mulch thus extends survival by 15 days and combined with mulch for 25 days, over double the period for the controls. The benefit of a mulch is shown by comparing T1b with T1a and T4b with T4a. It extends survival by around 9 days in each case.

Roots from plants treated with P4 grow better than controls (Plate 1), although differences were not quantified. It is clear also that roots frequently grow "through" polymer granules, since root systems removed from pots retain large numbers of granules; granules, being like beads on a string (root) and very firmly retained by the roots. It is not clear whether growing roots "seek out" granules as regions of high water availability, but this is possible. Since P4 stimulates root growth it is possible that this will be a secondary drought resisting feature of its use - a larger root system to exploit a greater volume of soil/water storage system in times when water is scarce.

Figure 3 Cumulative water lost to meter reading = 5

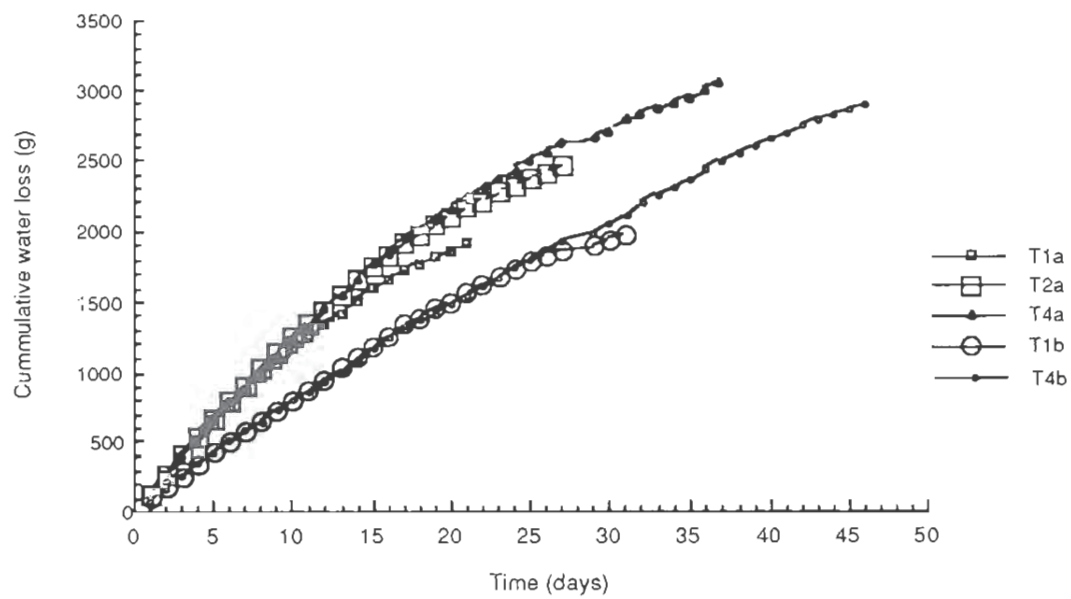
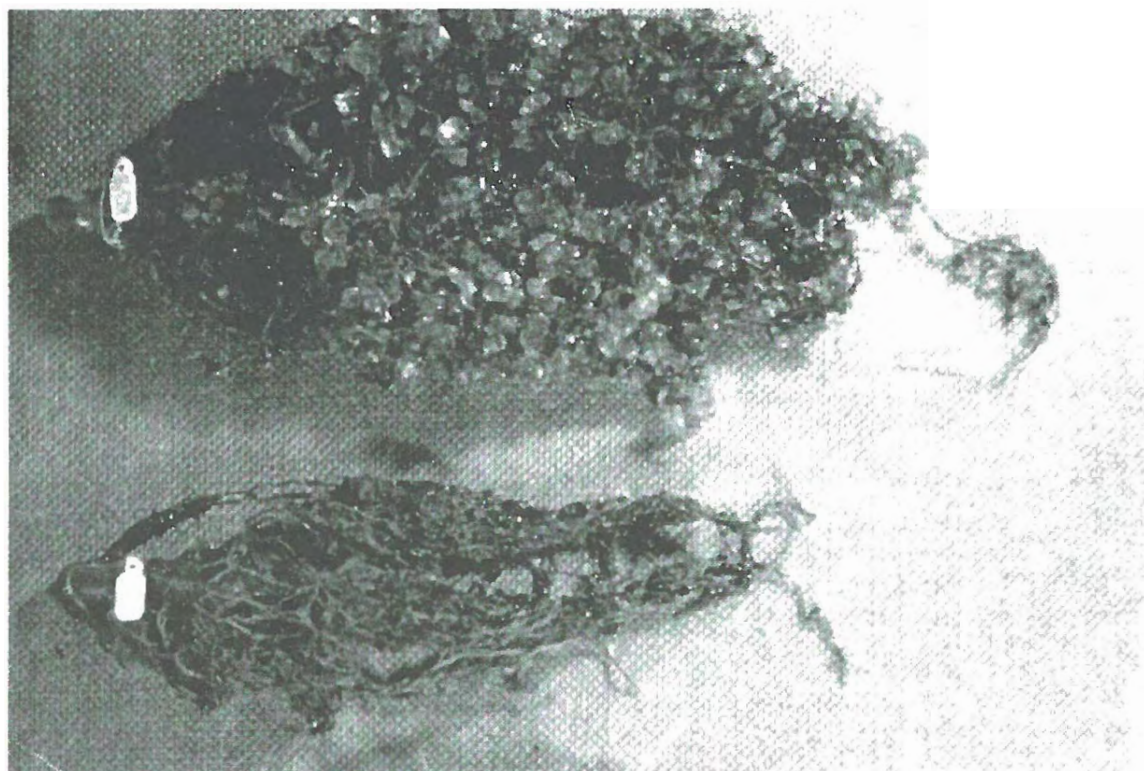


Plate 1 Root systems of seedlings grown in i) compost amended with 5 g l^{-1} - treatment T4 (upper), and ii) compost only, no P4 - treatment T1 (lower). Note many hydrated P4 granules attached to roots of T4 plant.



The mulch treatment also caused root development on the surface of composts, a phenomenon often observed in drying soils. With a mulch, water potentially lost through evaporation is trapped, creating a moist space between surface and mulch and the roots grow towards this zone.

Experiment 2i. Nursery: nursery transplantation

Figure 4d shows that total plant growth (combined leaf, stem and root dry weight) was greater for plants receiving P4 at transplantation (compare T1 with T3, T5 and T7; and T2 with T4, T6, T8 and T10). Plants subjected to a mulch treatment show better growth than non-mulched plants and better growth than those receiving only P4 addition (compare T2, T4, T6, T8 and T10 with T1, T3, T5, T7 and T9 respectively, i.e. T2 with T1; T3 with T4, etc.) Application of P4 to seedlings before transplantation and without subsequent mulching or P4 application was no better than not using P4 at all (compare T1 and T9) showing that P4 enhances growth and survival only if added at transplanting if mulching is not used on transplanting.

Growth of individual plant parts (Fig. 4a, b and c) were very similar in pattern to the response of the whole plant, i.e. organ proportions were largely unchanged, though there are some interesting variations. Clearly mulch alone promotes better shoot growth (stem and leaf) than polymer alone (compare T2 with T3, T4 and T7; and also T10 with T3, T5 and T7). The difference is due to production of more leaf rather than stem material. Root growth was better in treatments containing P4 than in those without it, and the application of polymer at transplanting was better in this instance than application during initial seedling growth (compare T3, T4, T5, T6, T7, T8 with T9 and T10). The explanation for this may be two-fold: although P4 generally promotes better root growth (see Experiment 1 results), even in the presence of adequate water, cocoa seedlings have been shown to commit more assimilates to roots and stem than to leaves as drought conditions develop (Deng *et al.*, 1990). Here, plants not mulched would have experienced drought conditions earlier.

A characteristic feature of plants in Treatments 1 and 9 was the loss during the experiment of most of the leaves they possessed before droughting was initiated, and also the death of their terminal buds. The latter probably led to a loss of apical dominance because re-watering resulted in the development of many lateral buds on each plant, giving rise to many lateral branches which were quite distinct from natural jorquettes formed by other plants.

Experiment 2ii. Nursery: field transplantation

Figure 5 shows data for total plant dry weight and individual dry weights of leaves, stem and root for each treatment. No significant treatment differences were found following ANOVA on the primary data. This shows that neither P4 nor mulch, separately or in combination, improved the establishment and growth as determined at the conclusion of the experiment. It is of course possible that if measurements had been made earlier, before the drought had become too severe, treatment differences may have been seen. The dry season which followed transplanting was a particularly severe one by Trinidad standards, and thus the treatments (P4 and/or mulch) may have improved seedling establishment under less severe, but still, development-restricting conditions. Clearly the undoubted potential benefit provided by P4 and mulch has its limits.

Figure 4 Treatment effect on dry weight of whole plant (a), leaves (b), stem (c) and roots (d)

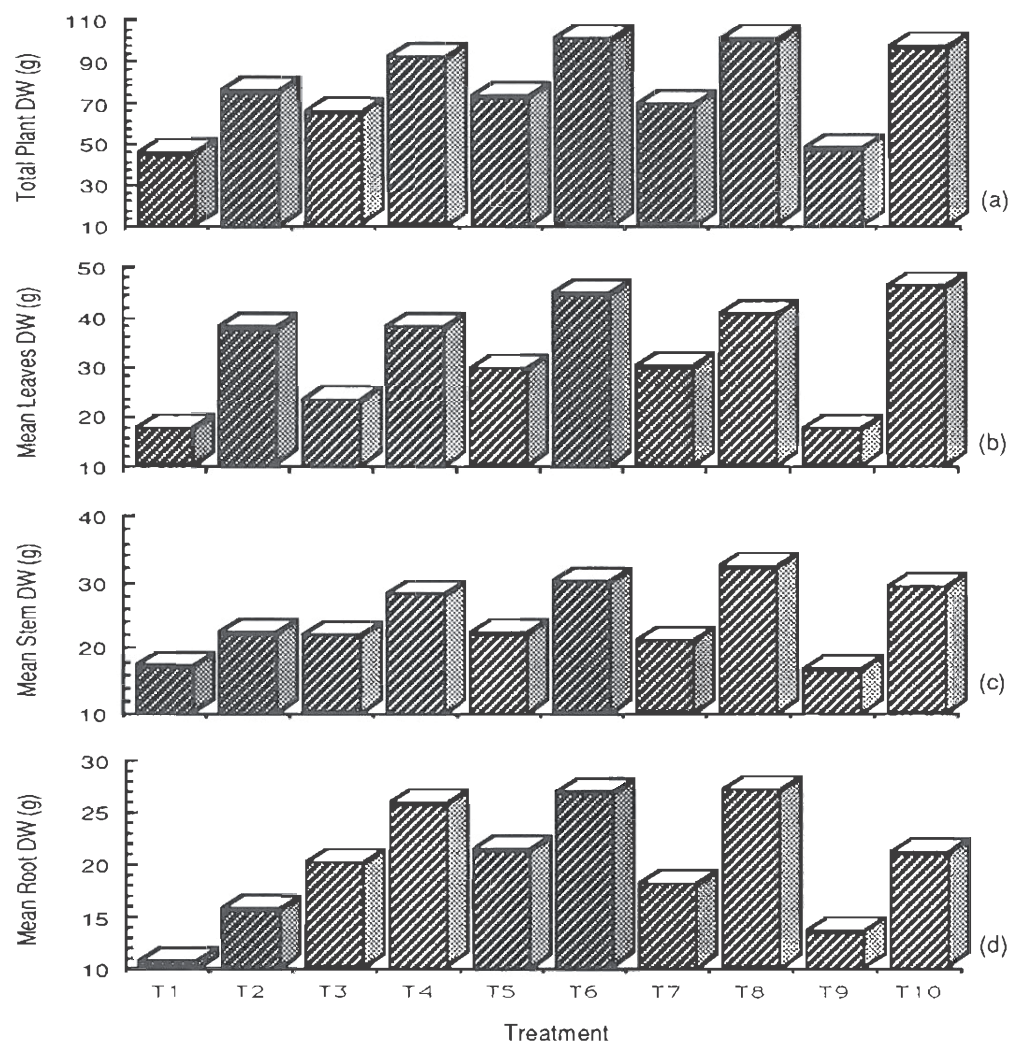
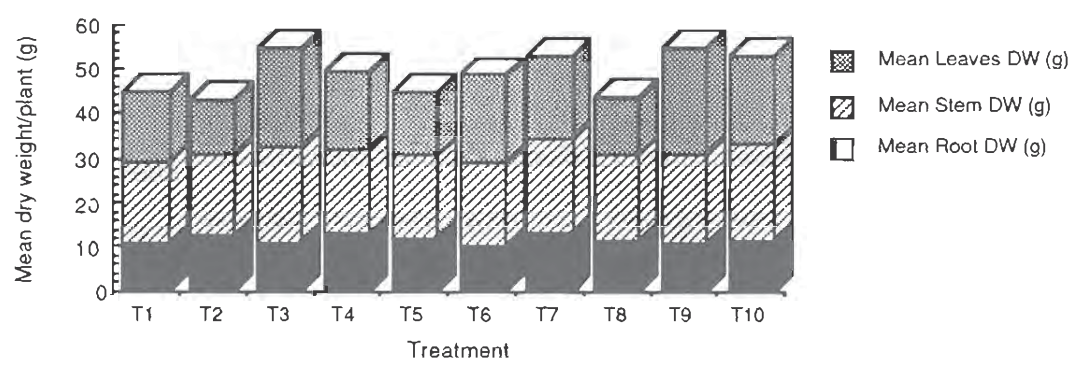


Figure 5 Treatment effect on total plant dry weight and component parts



When plants were harvested from the field, it was noted that seedling roots had not "grown through" polymer granules in the way found in the growth room and nursery situations. Water stored by polymer in the field would thus not have been so readily available to support plant growth. It is possible that in the severe drought conditions, water retained by P4 from initial irrigation was lost to the bulk soil within and outside the planting hole. Occasional irrigation of the field site, maybe with better mulching, could have restored the effectiveness of P4.

In the field site, the banana trees used for shading were already well established, as also were weeds; either could have been stronger competitors for water stored in the polymer granules. Indeed banana roots were frequently observed to have developed into the planting holes and grown through P4 granules, but significant numbers of hydrated P4 granules still had no roots attached. Weed growth was not controlled at the field site, but such control is advisable since Hodge (1990) has reported that under drought conditions for *Tilia platyphyllos*, *Fraxinus excelsior*, *Quercus petraea* and *Alnus glutinosa* transplants, weed control is a more effective ameliorative treatment than application of water retentive polymers.

For reasons beyond our control, the seedlings (which were quite large), were planted into the field in the early stages of the dry season. For maximum benefit from P4 or mulch it would be better to plant seedlings within a rainy phase so they are at least partially established and able to compete more effectively for soil water during the dry season.

Experiment 2iii. Bare-root tests

When bare-root stock was prepared, those seedlings raised with P4 retained many hydrated granules on the roots, similar to the upper root system on Plate 1; it was thus likely that water in the granules would maintain seedlings in a better physiological condition during exposure to air. This was true because at the end of the experiment, those raised with P4 in the nursery could easily be distinguished. All plants in the four treatments had satisfactorily established and retained all leaves that were mature at bare-rooting/transplantation. However, only plants raised with P4 retained new flush leaves present at transplanting. The P4 root-dip of bare-root stock did not, under the conditions described, improve seedling performance. The conclusion must be that if a bare-root transplant system is used, then better establishment (no loss of new flush leaves) will be achieved if seedlings are raised in P4 amended compost and the hydrated granules allowed to remain on roots at bare-rooting.

Conclusions and Recommendations

- i. Incorporation of a superabsorbent polymer such as P4 into compost used to raise cocoa seedlings in a nursery will maintain normal growth, protect them from drought stress, and, it can be anticipated, reduce the amount and frequency of watering required to maintain healthy and uniform seedling development.
- ii. Following transplantation of seedlings within a nursery into large containers to simulate a field transfer, performance under drought is better with P4 mixed into the compost. It is also better if an effective mulch is applied. If mulching is not practised at transplanting, P4 is more effective when applied to the planting hole than if incorporated into the compost used to raise seedlings in the nursery.
- iii. It is clear that P4 makes more water available, but, without a mulch treatment, when there is a high rate of evaporative water loss to atmosphere under dry conditions, P4 effectiveness is limited. It is therefore best to combine P4 with a mulch treatment.

- iv. Although P4 (and mulching) will provide a buffer against drought damage to seedlings, the protection afforded is limited. It should be possible to predict from data on water use by cocoa seedlings under a range of environmental conditions (now being collected) and the water retention:release capacity of any polymer, the average days of extended survival that would be given from polymer use at certain levels. Polymer cost will ultimately determine the overall feasibility of its use.
- v. The manufacturer's recommended rate of application of the polymer P4 at 1 g l^{-1} is insufficient for cocoa seedlings of the size normally planted into the field. We would recommend rates of 3 or 5 g l^{-1} in compost used to raise seedlings in the nursery with about 40 g added to the planting hole at transplanting.
- vi. Establishment of seedlings transplanted in a bare-root state was improved if P4 was added (at 3 g l^{-1}) to the compost used to raise seedlings in the nursery. P4 used only as a root-dip to bare-root stock did not improve establishment under the conditions used. Further refinement of P4 use for bare-root stock could prove worthwhile.
- vii. Data on the parameters referred to in iv., together with information on the ability of P4 to carry and release inorganic (fertilizer) and organic (pesticides and fungicides) compounds at controlled rates into soil are now being assembled.

Acknowledgements

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