# Effects of moisture stress on growth and nutrient uptake in cacao seedlings

F. M. AMOAH
*Cocoa Research Institute of Ghana, P. O. Box 8, Akim-Tafo, Ghana*

ABSTRACT

The effects of four moisture stress regimes on plant growth and uptake of nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca) were studied in 3-month-old seedlings of three cacao cultivars grown in plastic pots under glass-house conditions. The objective was to determine watering regimes that favoured vigorous growth of the seedlings. The experiment was a 3 × 4 factorial in a randomised complete block design with three replicates. The moisture stress treatments studied were watering to pot capacity daily, watering to pot capacity on every 4th day, watering to pot capacity on every 8th day, and watering to pot capacity only when plants showed signs of wilting (10-12 days intervals). The moisture stress treatments were applied for 12 weeks. Increasing levels of moisture stress resulted in decreased seedling growth rate, reduced relative water content (RWC) , and increased level of leaf scorching. It also resulted in decreasing amounts of N, P, K, Ca and Mg (mg $g^{-1}$) in leaves and stem. Cacao cultivar PA7 was more susceptible to moisture stress than UIT1 and SCA12 in that order. The interaction effects of cultivar and moisture stress treatment on seedling growth and nutrient uptake were not significant. Results of this study suggest that cacao seedlings raised in the nursery may be watered to pot capacity daily for healthier growth and development.

Original scientific paper. Received 21 Aug 03; revised 15 May 04.

RÉSUMÉ

AMOAH, F. M.: *Effet de la pression d'humidité sur la croissance et l'absorption de substance nutritive des semis de cacao.* Les études se sont déroulées sur les effets de quatre échantillons de la pression d'humidité sur la croissance et l'absorption d'azote (A), phosphore (P), potassium (K), magnésium (Mg), et calcium (Ca) par les semis, agés de trois mois, de trois variétés de cacao semés dans les pots en plastique sous les conditions de la serre. Le but était de déterminer l'échantillon d'arrosage qui favorisait la croissance vigoureuse des semis. L'expérience était d'un factoriel 3 × 4 dans un dessin de bloc complet choisi au hasard avec trois replicatifs. Les traitements de pression d'humidité étudiés étaient: (1) arrosage quotidien à la capacité du pot, (2) arrosage à la capacité du pot chaque quatrième jour, (3) arrosage à la capacité du pot chaque huitième jour, et (4) arrosage à la capacité du pot lorsque les plantes montraient les signes de dessèchement (intervalle de dix à douze jours). Les traitements de pression d'humidité étaient appliqués pour 12 semaines. L'augmentation des niveaux de la pression d'humidité menait à une diminution de proportion de croissance du semis, réduction du contenu d'eau relative (RCE), augmentation du niveau de brûlure de feuille et une diminution de la quantité d' A, P, K, Ca et Mg (mg $g^{-1}$) dans les feuilles et la tige. La variété PA7 de cacao était plus susceptible à la pression d'humidité que les variétés UlTl et SCA 12 dans l'ordre logique. Il n'y avait pas d'effet d'interaction considérable de la variété et le traitement de pression d'humidité sur la croissance de semis et l'absorption de substance nutritive. Les résultats de cette étude suggère que les semis de cacao soignés dans les pépinières pourraient être arrosé à la capacité de pot quotidiennement pour la croissance et le développement plus saines.

## Introduction

Cacao *(Theobroma cacao)* is highly sensitive to changes in environmental factors, especially moisture supply (Wood & Lass, 1985). Several workers have studied the effect of moisture stress on mature cacao (McDonald, 1932; Lemee, 1955;

Alvim, 1959, 1960). Water relations in mature cacao affects several other development processes such as photosynthesis, yield, cherelle wilt, incidence of diseases and pests, and longevity of the tree. Hutcheon (1971) observed that a period of drought or moisture stress followed by rainfall or watering triggers off flushing and flowering. However, information on water relations in young cacao is limited. Evidence, however, suggests that young cacao is more susceptible to moisture stress than mature cacao (Hutcheon, 1972). Hutcheon (1971) stated that excess soil moisture is as harmful to the growth of cacao seedlings as inadequate moisture, particularly in soils that are rich in organic matter and have high water-holding capacity.

Hutcheon (1971) observed that the diurnal variation in leaf tension, as reported in mature cacao, also exists in seedlings and has been shown to closely follow the diurnal pattern of transpiration as measured by weighing a potted seedling. The internal moisture status of young plants with a small root system, and of plants growing in containers is quite sensitive to changes in soil moisture. The rate of development of cacao seedlings in the nursery depends on the supply of moisture and its subsequent effect on nutrient uptake from the soil. An apparently rich soil may produce deficiency symptoms in young cacao due to irregular or limited moisture supply. However, the degree of moisture stress, which induces these deficiencies in young cacao, is unknown.

In Ghana, cacao seedlings for new establishments are normally raised from December to March when moisture is scarce and watering of the young plants becomes irregular due to water shortage. For healthy development of cacao seedlings in the nursery, it is expedient to determine the optimum watering frequency as it affects growth and nutrient uptake.

The objective of this paper was to study the effects of moisture stress on growth and macro-nutrient uptake and distribution in young cacao plants. This will help determine the frequency at which potted seedlings should be watered for healthy growth and development.

## Materials and methods

Three-month-old seedlings of cacao cultivars PA7, SCA12, and UIT1 were used for this study in the glass-house. The cocoa seeds were pre-germinated in perlite for 4 weeks after which uniform seedlings were selected and planted in compost (3:1, peat:grit) in 20-cm$^3$ plastic pots. The experiment was a 3 × 4 factorial in a randomised complete block design with three replicates. Thirty plants were in each sub-plot. The glass-house temperature was 30°/20 °C (day/night) throughout the experiment. Four moisture stress treatments were investigated:

- T1 - Watering to pot capacity daily
- T2 - Watering to pot capacity on every 4th day
- T3 - Watering to pot capacity on every 8th day
- T4 - Watering to pot capacity only when plants showed signs of wilting (10 - 12 days intervals)

The plants in each treatment were given a liquid feed of Cooper's solution (Cooper, 1979) at 4-week intervals, starting at 4 weeks after sowing.

The water-holding capacity of the compost was about 48 per cent. Sample plants were collected at 4 weekly intervals for growth and chemical analyses. The plants were partitioned into leaves, stem, and roots for growth analysis. Data were collected on plant height, girth, leaf number, leaf area, root volume, and fresh and dry weights of the various plant parts. Stem girth was measured at 8.0 cm from the soil surface. Dry weight was determined after oven-drying the samples at 80 °C for 48 h. Root volume was determined by the methods of Andrew (1966) and Pinkas (1964), based on the principle of displacement of a volume of water equal to the volume of the object immersed in the water.

The water status of the plants was assessed by punching discs from the leaves to determine relative water content (RWC), using the methods of Weatherly (1950) and Barrs & Weatherly (1962) that are also based on floatation and turgidity in leaf discs. The plants were visually assessed for the degree of leaf scorching, based on the percentage of total leaf area scorched, on scale 0 to 100 per cent: where 0 per cent indicates no scorching; 50 per cent, half of the leaf scorched; and 100 per cent indicates whole leaf scorched. Leaf and stem samples were also analysed at 4-week intervals for N, P, K, Ca and Mg, using the method of the Ministry of Agriculture, Fisheries and Food (MAFF, 1981) of the United Kingdom. Ashing and digestion methods were used for the chemical extraction of elements.

## Results

Moisture stress treatment strongly influenced growth of the seedlings. However, no interaction effects were recorded between cultivar and moisture stress treatments. Plants watered daily (T1), or on every 4th day (T2) produced significantly better results in growth ($P \leq 0.01$) than plants watered on every 8th day (T3), or only when signs of wilting (T4) were observed. The differences between T1 and T2 in all the growth parameters were not significant (Table 1). However, growth parameter values for TI plants were slightly higher than those for T2 plants in all the three cultivars.

Cacao cultivar UIT1 had the highest values in most growth parameters, followed in a decreasing order by PA7 and SCA12. Leaf scorching was almost negligible in T1 plants (Table 2). Treatments 3 and 4 plants had significant percentage of their total leaf area scorched compared to T1 and T2. Table 3 shows that after the 4th and 8th week, T1 and T2 plants had significantly higher RWC than T3 and T4 plants ($P \leq 0.05$). Treatment 1 plants were also significantly higher than T2 plants in RWC after the 8th week ($P \leq 0.05$). After the 12th week, the RWC of T1 plants was found to be the highest, followed in a decreasing order by T2, T3 and T4 plants. Treatment 3 plants were also significantly higher in RWC than T4 plants ($P \leq 0.05$) after the 12th week.

TABLE 1

*Effect of Moisture Stress on Growth Parameters in Three Cacao Cultivars After 12 Weeks*

| *Cacao cultivar* | *SCA12* | | | | *UIT1* | | | | *PA7* | | | | *LSD* $P \leq 0.05$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Parameter* | *T1* | *T2* | *T3* | *T4* | *T1* | *T2* | *T3* | *T4* | *T1* | *T2* | *T3* | *T4* | |
| Leaf number | 15.4 | 15.6 | 12.7 | 13.6 | 20.2 | 19.6 | 17.2 | 17.8 | 18.3 | 18.5 | 14.5 | 15.7 | 4.80 |
| Leaf fresh weight (g) | 18.0 | 15.0 | 7.1 | 5.0 | 23.7 | 20.8 | 10.5 | 7.5 | 20.7 | 17.0 | 7.9 | 5.5 | 5.25 |
| Stem fresh weight (g) | 10.0 | 7.3 | 3.5 | 3.1 | 14.1 | 9.2 | 4.8 | 4.0 | 11.9 | 8.4 | 4.0 | 3.1 | 3.72 |
| Root fresh weight (g) | 8.1 | 2.9 | 2.0 | 1.9 | 11.7 | 5.6 | 3.3 | 3.0 | 9.9 | 4.1 | 2.5 | 2.3 | 5.43 |
| Leaf dry weight (g) | 6.2 | 5.4 | 2.4 | 2.1 | 8.5 | 7.9 | 4.6 | 3.8 | 7.2 | 6.8 | 3.2 | 2.8 | 2.14 |
| Stem dry weight (g) | 2.2 | 1.9 | 0.9 | 0.7 | 4.5 | 3.1 | 1.8 | 1.3 | 3.5 | 2.8 | 1.2 | 1.0 | 1.85 |
| Root dry weight (g) | 2.6 | 1.4 | 9.0 | 0.6 | 3.3 | 2.3 | 1.4 | 1.0 | 2.8 | 2.0 | 1.0 | 0.8 | 2.44 |
| Total plant fresh weight (g) | 32.2 | 24.0 | 11.2 | 9.2 | 53.7 | 35.2 | 19.3 | 14.4 | 42.5 | 30.8 | 15.4 | 10.3 | 8.46 |
| Total plant dry weight (g) | 12.0 | 10.0 | 4.2 | 3.6 | 15.5 | 13.5 | 7.3 | 6.0 | 13.3 | 11.1 | 5.9 | 4.5 | 3.92 |

T1 = Watering to pot capacity daily
T2 = Watering to pot capacity on every 4th day
T3 = Watering to pot capacity on every 8th day.
T4 = Watering to pot capacity when plants showed signs of wilting (10-12 days' intervals)

TABLE 2

*Effect of Moisture Stress on Percentage Leaf Area Scorched in Three Cacao Cultivars*

| *Cocoa cultivar* | | *SCA12* | *UIT1* | *PA7* | *Mean* | *LSD (P≤0.05)* |
|---|---|---|---|---|---|---|
| *Treatment* | T1 | 1.0 | 1.0 | 1.0 | 1 | |
| | T2 | 2.0 | 4.0 | 3.0 | 3 | |
| 4 weeks | T3 | 42.0 | 46.0 | 56.0 | 48.0 | 15.23 |
| | T4 | 25.0 | 32.0 | 33.0 | 30 | |
| | T1 | 2.0 | 2.0 | 2.0 | 2 | |
| | T2 | 4.0 | 5.0 | 6.0 | 5 | |
| 8 weeks | T3 | 36.0 | 40.0 | 44.0 | 40 | 18.42 |
| | T4 | 40.0 | 52.0 | 58.0 | 50 | |
| | T1 | 2.0 | 2.0 | 2.0 | 2 | |
| | T2 | 16.0 | 18.0 | 20.0 | 18 | |
| 12 weeks | T3 | 40.0 | 56.0 | 60.0 | 52 | 17.65 |
| | T4 | 44.0 | 50.0 | 56.0 | 50 | |
| Means | | 21.2 | 25.6 | 28.4 | | |
| LSD (*P*≤0.05) | | | NS | | | |

T1 = Watering to pot capacity daily
T2 = Watering to pot capacity on every 4th day
T3 = Watering to pot capacity on every 8th day
T4 = Watering to pot capacity when plants showed signs of wilting (10-12 days' intervals)

TABLE 3

*Effect of Moisture Stress on Relative Water Content (%) in Three Cacao Cultivars*

| *Cocoa cultivar* | | *SCA12* | *UIT1* | *PA7* | *Mean* | *LSD (P≤0.05)* |
|---|---|---|---|---|---|---|
| *Treatment* | T1 | 97.6 | 98.9 | 98.8 | 98.4 | |
| | T2 | 95.6 | 87.8 | 84.6 | 87.6 | |
| 4 weeks | T3 | 80.2 | 74.2 | 72.4 | 75.6 | 10.21 |
| | T4 | 78.1 | 72.1 | 66.2 | 72.1 | |
| 8 weeks | T1 | 95.8 | 95.2 | 94.5 | 95.1 | |
| | T2 | 97.2 | 90.4 | 84.3 | 90.6 | |
| | T3 | 82.1 | 77.2 | 76.1 | 78.5 | 8.45 |
| | T4 | 82.5 | 80.4 | 76.1 | 79.6 | |
| 12 weeks | T1 | 98.5 | 98.3 | 97.8 | 98.2 | |
| | T2 | 95.4 | 90.2 | 84.1 | 89.9 | |
| | T3 | 84.2 | 82.6 | 78.8 | 81.9 | 8.86 |
| | T4 | 78.0 | 72.6 | 68.3 | 72.9 | |
| Mean for cultivars | | 88.8 | 84.9 | 81.8 | | |
| LSD (*P*≤ 0.05) | | | NS | | | |

T1 = Watering to pot capacity daily
T2 = Watering to pot capacity on every 4th day
T3 = Watering to pot capacity on every 8th day
T4 = Watering to pot capacity when plants showed signs of wilting (10-12 days' intervals)

No significant differences were recorded among cultivars in percentage leaf area scorched as well as RWC.

However, SCA12 plants were observed to be most tolerant to moisture stress compared to either UIT1 or PA7 plants at all stages of growth. Cultivar PA7 plants were observed to be the most susceptible to the stress treatment, with the highest percentage of total leaf area scorched at all stages of growth and the least RWC (Tables 2 and 3).

Fig. 1, 2, 3, 4 and 5 show the effects of the moisture stress treatments on the concentrations of N, P, K, Ca, and Mg in the leaves and stem of young cacao. No major effects were observed due to cultivar or cultivar by moisture stress interaction; hence, the results show the mean effect of stress treatment on the three cultivars.

In general, increasing moisture stress resulted in decreasing amounts of all the major elements determined in leaves and stem. Treatments 1 and 2 were significantly higher ($P \leq 0.001$) in the major nutrients than T3 and T4 at most harvesting dates (Fig. 1-5). Treatment 3 also yielded significantly higher results than T4 at most harvesting dates, especially in leaf nutrients (Fig. 1-5). The levels of N, K and Ca were clearly higher in leaves than stem. However, the levels of Mg in stem and leaves at the various harvesting dates did not follow any regular trend (Fig. 5). The levels of P in stem were, however, always higher than the corresponding levels in the leaves in all treatments (Fig. 2).

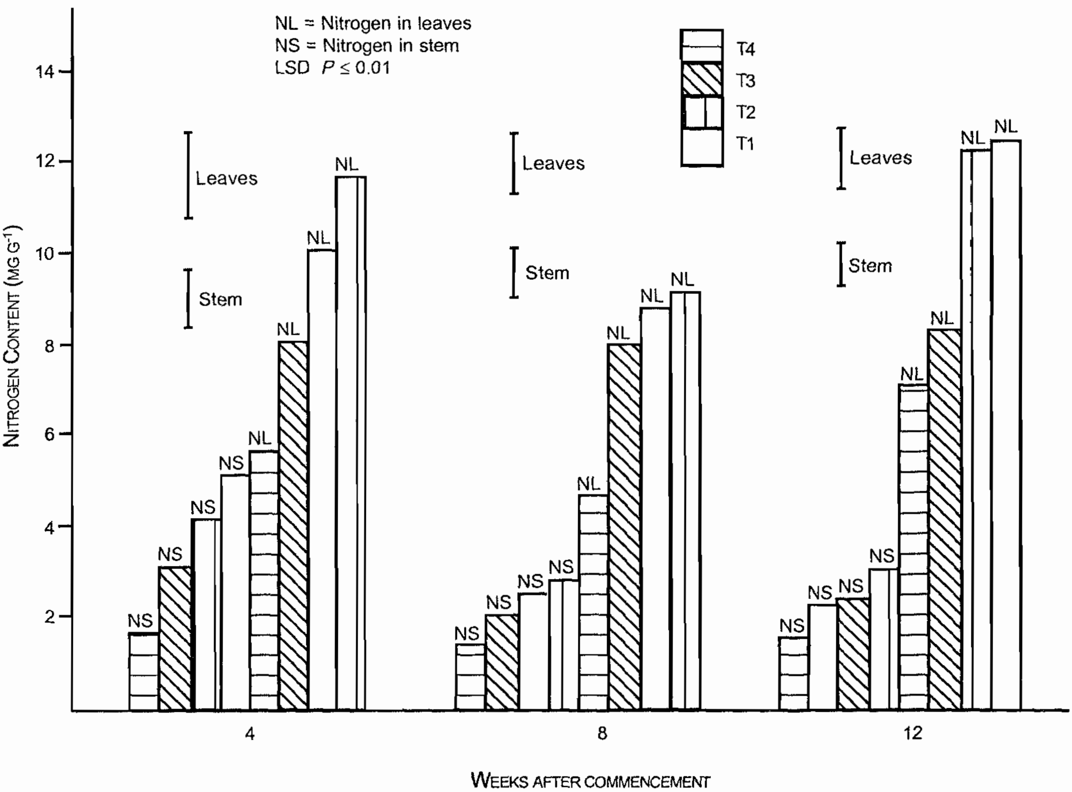


Fig. 1. Nitrogen nutrition in young cacao seedlings in relation to moisture stress treatments.

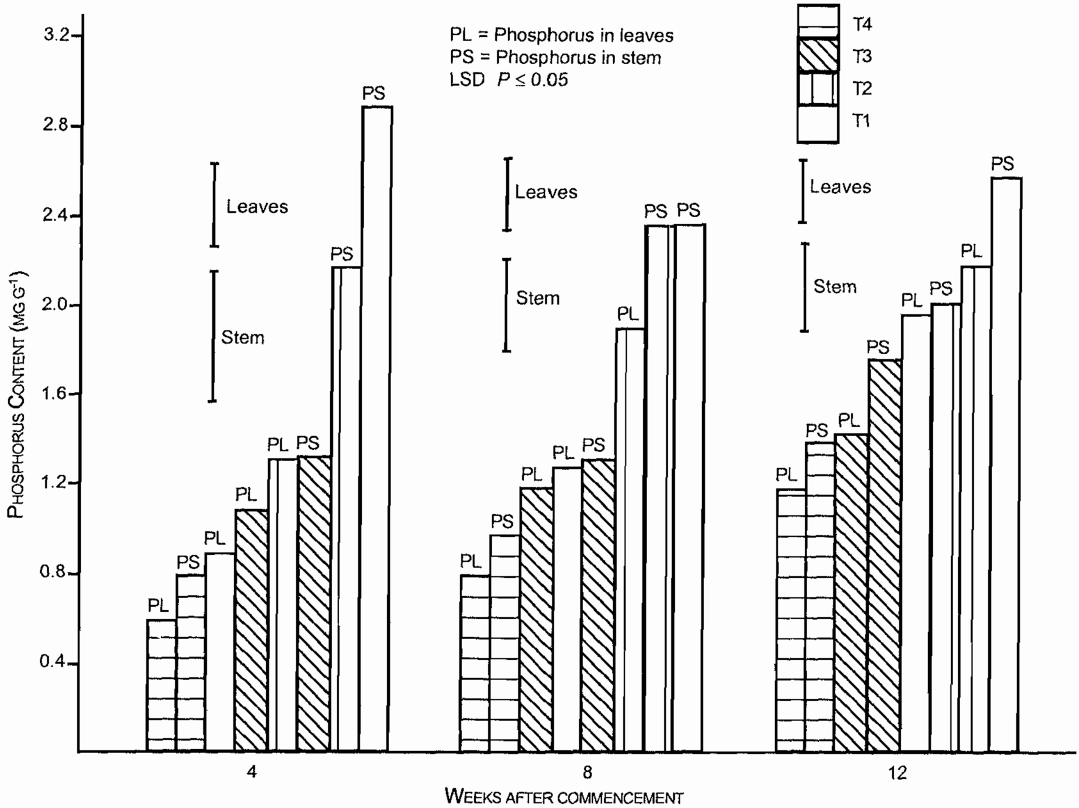


Fig. 2. Phosphorus nutrition in young cacao seedlings in relation to moisture stress treatments.

## Discussion

The growth of plants in compost and mineral nutrition were significantly affected by the frequency of watering. The results of this study indicate that one of the causes of poor growth and marginal leaf scorching in cacao is insufficient or irregular watering. Increasing levels of moisture stress resulted in degenerating growth of seedlings.

The best growth was recorded for daily watering of plants to pot capacity. As observed by Khairi & Hall (1976), mesophyll conductance to $CO_2$ probably increases with increasing frequency of watering, which results in increased rate of photosynthesis and *vice versa*. The poor growth in seedlings induced by increasing levels of moisture stress could also be due to the inhibition effect of accumulation of abscisic acid with increasing degree of moisture stress (Wright, 1969; Wright & Hiron, 1969; Simpson & Sanders, 1972; Zeevart, 1971; Rasmussen, 1976).

As over-watering could also lead to anaerobic conditions in the growing media which could adversely affect the root system and, hence, plant growth (Hutcheon, 1972), a more regular supply of moisture in sufficient amounts should be provided to plants under nursery conditions. Thus, optimum levels of moisture to be provided should be calculated in relation to the physical properties of the potting media and local environmental conditions.

Increasing levels of moisture stress resulted in reduced levels of macro-nutrients directly related to the growth of plants. The amounts of nutrients

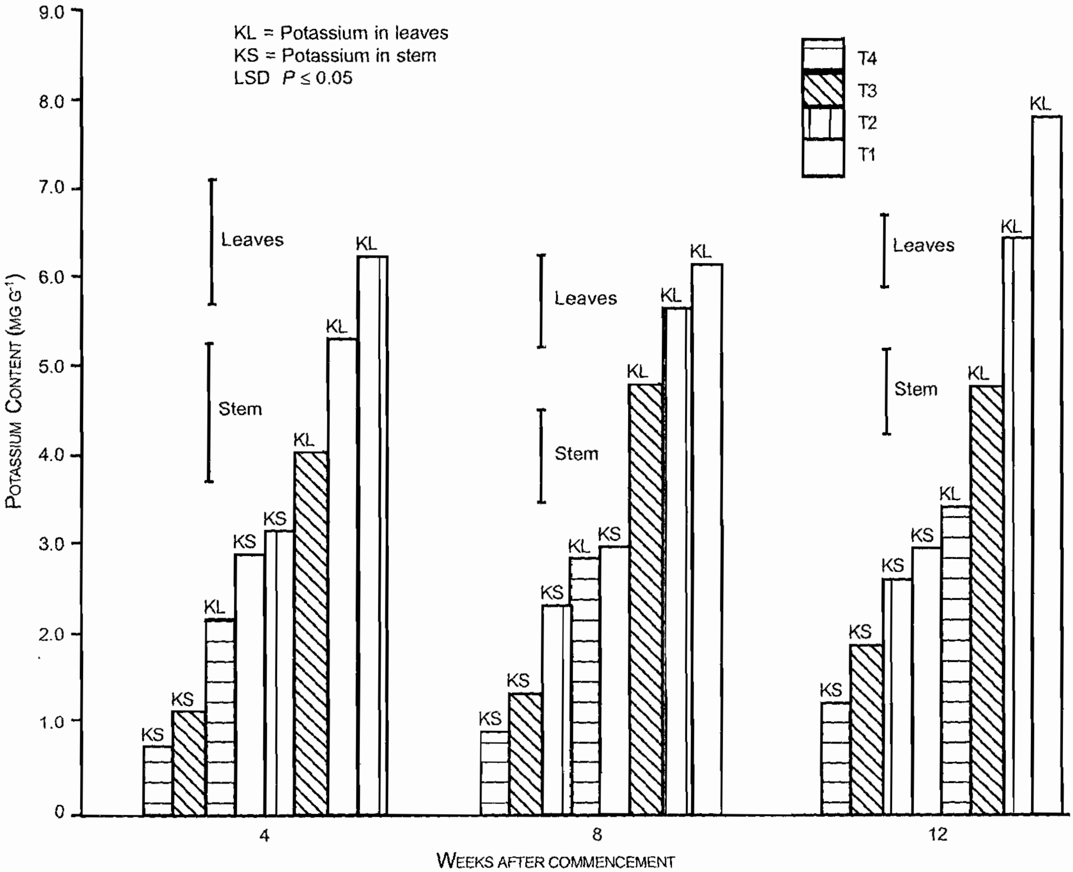


Fig. 3. Potassium nutrition in young cacao seedlings in relation to moisture stress treatments.

taken up by the plants possibly affected their metabolic processes. With higher nutrient uptake, growth is enhanced through cell division and expansion (Wareing & Philips, 1985), which is translated into accelerated growth of plants in the less or no stress treatments. Under high moisture stress, stomata aperture and mesophyll conductance to $CO_2$ is reduced (Greenwood & Collier, 1980). This results in reduced photosynthetic activity. As photosynthates constitute the building block of plant tissues, moisture stress treatments result in reduced rate of plant growth.

Whilst the trend in the distribution of N, K, Ca and P between stem and leaves was regular, the distribution of Mg did not follow any regular trend. However, Gur, Hepner & Shulman (1979) noted that the distribution of nutrients between various plant organs was dependent on factors such as temperature, plant age, and the supply of nutrients.

Several reports indicate that the uptake of a particular nutrient may be affected by the levels of other nutrients. For example, Bedi & Sekhon (1977) observed that the uptake of calcium is affected by other cations, with hydrogen, ammonium, potassium and magnesium being particularly effective in impeding calcium uptake.

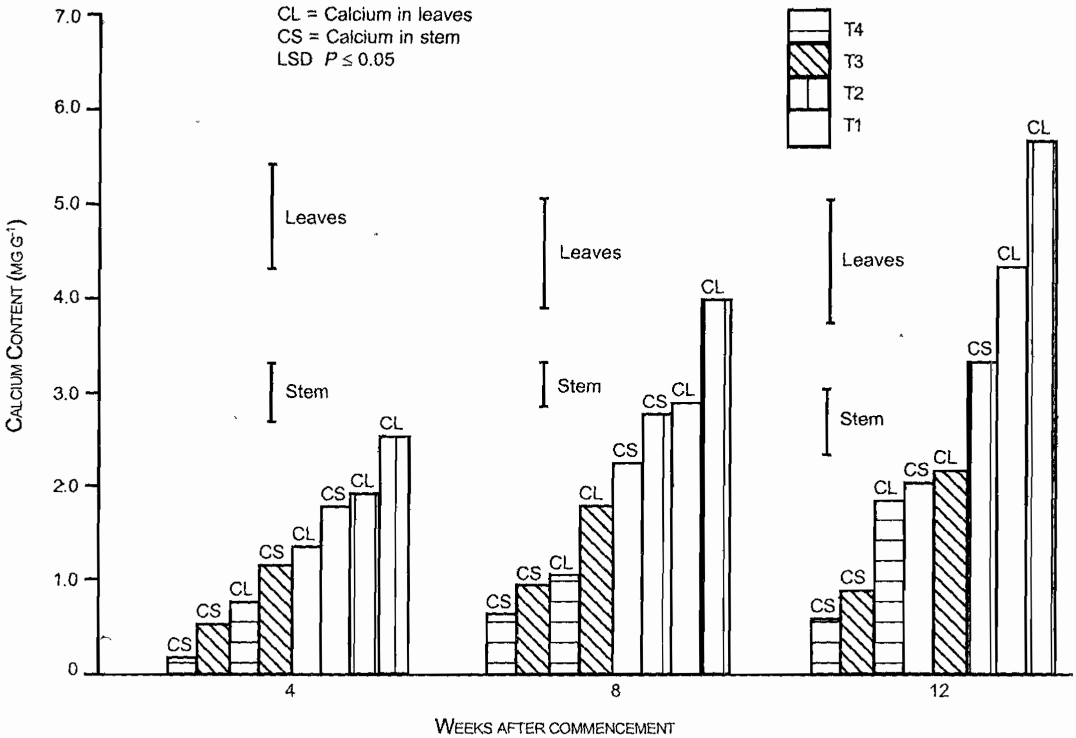


Fig. 4. Calcium nutrition in young cacao seedlings in relation to moisture stress treatments.

Fordham & Biggs (1985) also stated that excessive K can reduce Mg and Ca uptake, whilst excess P can also reduce the availability of K and Mg. These results suggest antagonistic effect in uptake of nutrients by plants, and this probably explains the lack of regular trend in uptake and distribution of nutrients in this study.

The trend of results in this study is particularly significant for calcium nutrition, which could be related to the incidence of marginal leaf scorching than to any other macro-nutrient. Because plants which were severely scorched had lower amounts of calcium in the leaves. Unlike most nutrients, calcium is not transported in the phloem with a high *p*H and high levels of phosphorus (Greenwood & Collier, 1980) which would cause calcium entering the phloem to be precipitated as calcium phosphate. The distribution of nutrients to the leaves and stem in this study showed that, generally, the leaves contained more N and K than the stem. Calcium and magnesium were highest in the stem. The uptake of calcium ions by plant roots is confined to a small segment of unsuberised root near the tip, in contrast to other nutrients absorbed over a much greater length of root (Drew & Clarkson, 1978).

Apart from the effect of moisture availability to plants, environmental factors such as dull and humid conditions, which lower transpiration rates, could indirectly cause calcium deficiency in plants through reduced water uptake (Adams & Ho, 1985). Such observations have been made in plants raised in the glass-house with high humidity levels (Adams & Ho, 1985). High osmotic potential in the root zone of plants caused by high nutrient concentration can also reduce water uptake and, hence, calcium deficiency in plants. A major symptom of calcium deficiency in many plants is marginal leaf scorching, the effect of localised shortage of calcium in the scorched areas.

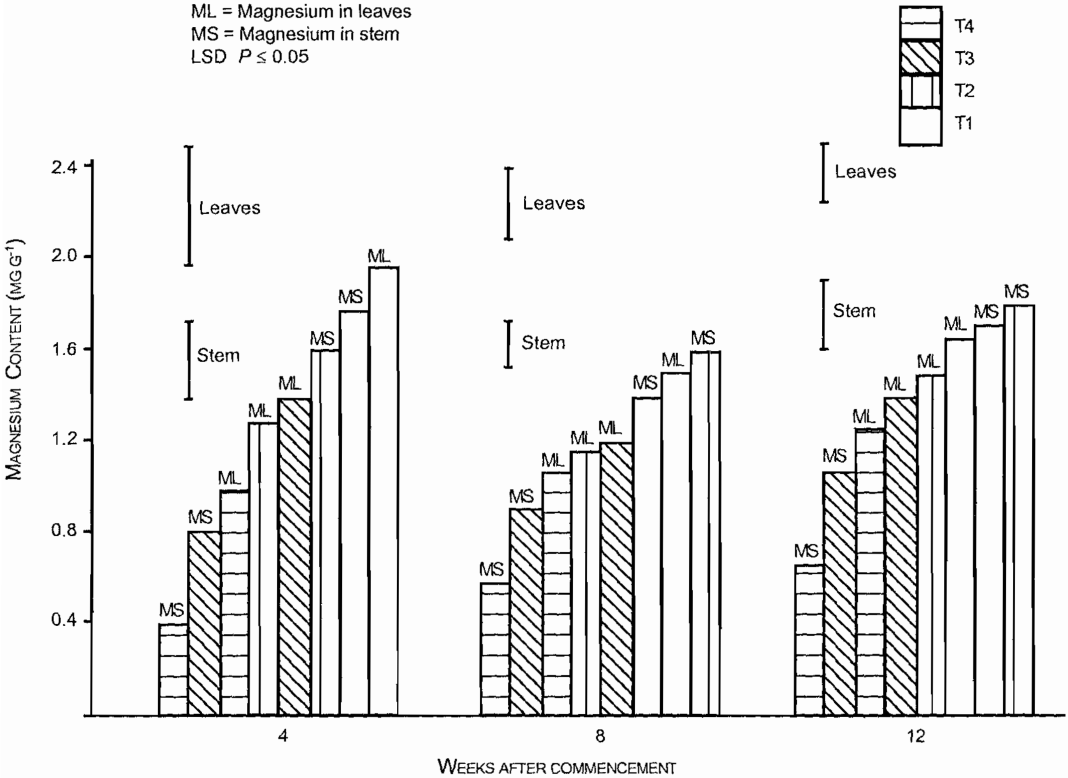


Fig. 5. Magnesium nutrition in young cacao seedlings in relation to moisture stress treatments.

This study recorded similar observations. This results in reduced cell wall and calcium pectate in the affected areas in the leaves (Greenwood & Collier, 1980).

As plant nutrients are taken up through moisture uptake, an inherently rich soil may produce deficiency symptoms in plants under limited moisture conditions. On the other hand, over-watering or water-logging causes oxygen supply to roots to be severely reduced, and this could result in root decay and consequent death of plants. For healthy growth of plants, therefore, the moisture-holding capacity of the soil is relevant. It is also important that adequate amount of water be supplied at regular intervals.

This study suggests that cocoa seedlings raised in the nursery should be watered to pot capacity daily for healthier growth and development. Watering every 4 days is also acceptable, but the vigour of seedling growth is reduced.

### *Acknowledgement*

The author thanks Mrs Esther Ankrah for the preparation of the manuscript. This paper is published with the permission of the Executive Director of Cocoa Research Institute of Ghana.

## REFERENCES

**Adams, P. & Ho, L.** (1985) Two disorders but one cause. *Grower*, March 21, 1985, pp. 20-25.

**Alvim, P. de T.** (1959) *Water requirements of cacao.* First FAO Technical Cacao Meeting, Accra, February 1959.

**Alvim, P. de. T.** (1960) Stomatal opening as a practical indicator of moisture deficiency in cacao. *Phyton.* **15,** 79-89.

**Andrew, R. H.** (1966) A technique for measuring root volume *in vivo*. *Crop Sci. J.* **6,** 384-386.

**Anon** (1981) *The analysis of agricultural materials* – 2nd ed. Annual Report of the Analytical Methods used by ADAS, London, HMSO. 226 pp.

**Barrs, H. D. & Weatherly, P. E.** (1962) A re-examination of the relative turgidity technique for estimating water deficits in leaves. *Aust. J. biol. Sci.* **15,** 413-428.

**Bedi, A. S. & Sekhon, G. S.** (1977) Effect of potassium and magnesium application to soils on dry matter yield and composition of maize. *J. agric. Sci.* **88,** 753-758.

**Cooper, A. J.** (1979) *The ABC of NFT.* Grower Books. London. 181 pp.

**Drew, M. C. & Clarkson, D. T.** (1978) The growth and function of the root system in relation to maximum yield. In *Maximising yield of crops* (ed. J. K. R. Gasse and B. Wilkinson), pp. 50-56. London: HMSO.

**Fordham, R. & Biggs, A. G.** (1985) *Principles of vegetable crop production*. Collins, London. 25 pp.

**Greenwood, D. J. & Collier, G. F.** (1980) Recent progress in the nutrition of vegetable crops. In *Opportunities for increasing crop yield* (ed. R. G. Hurd, P. V. Biscre and C. Dennis), pp. 115-130. Pitman Advanced Publishing program, Boston, London, Melbourne, 410.

**Gur, A., Hepner, J. & Shulman, Y.** (1979) The influence of root temperature on apple trees. IV. The effect on the mineral nutrition of the tree. *J. hort. Sci.* **54**(5), 313-321.

**Hutcheon, W. V.** (1971) *The development of moisture stress in cocoa.* Rep. Cocoa Res. Inst. Ghana. 195-203.

**Hutcheon, W. V.** (1972) *The water relations of cocoa.* Rep. Cocoa Res. Inst. Ghana. pp. 149-165.

**Khairi, M. M. A. & Hall, A. E.** (1976) Temperature effects on net photosynthesis and transpiration of citrus. *Physiologia Pl.* **36,** 29-34.

**Lemee, G.** (1955) Influence de l'alimentation en eau er de limbrage sur l'economie hydrique et la photosynthese du cacoyer. *Agron. trop.* **10,** 592-603.

**McDonald, J. A.** (1932) An environmental study of the cacao tree. In *Annual Report on Cacao Research* **1,** 29-38. Imperial College of Tropical Agriculture. Trinidad.

**Pinkas, L. L. H.** (1964) A method of measuring the volume of small root systems. *Agron. J.* **56,** 90-91.

**Rasmussen, O. S.** (1976) Water stress in plants. 1. Abscisic acid level in tomato leaves after a long period of wilting. *Physiologia Pl.* **36,** 208-212.

**Simpson, G. M. & Sanders, P. F.** (1972) Abscisic acid associated with wilting in dwarf and tall sativum. *Planta* **102,** 272-276.

**Wareing, A. T. & Philip, G.** (1985) *Growth and differentiation in plants.* Longman, London, New York. 450 pp.

**Weatherly, P. E.** (1950) Studies in the water relations of the cotton plant. 1. The field measurement of water deficit in leaves. *New Phytol.* **49,** 81-97.

**Wood, G. A. R. & Lass, T. A. (ed)** (1985) *Cocoa,* 4th ed. Longman, London and New York.

**Wright, S. T. C.** (1969) An increase in the inhibitor B content of detached wheat leaves following a period of wilting. *Planta* **86,** 10-20.

**Wright, S. T. C. & Hiron, R. W. P.** (1969) (+) Abscisic acid, the inhibitor in detached wheat leaves following a period of wilting. *Nature* **224**, 719-720.

**Zeevart, J. A. D.** (1971) (+) Abscisic acid content of spinach in relation to photoperiod and water stress. *Pl. Physiol.* **48,** 86-90.