Root growth and nutrient flux of cowpea under field conditions

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Abstract

Field studies were conducted on an Egbeda soil series *(Oxic Paleustalf)* to determine the root length, root surface area and the nutrient flux into cowpea root at five days intervals of growth from 5 to 50 days after emergence. In companion study, a solution culture study was conducted in the greenhouse to determine if information from greenhouse investigations are valid indices of field situations regarding the characteristic changes in root growth with age of cowpea. A speculation was made from the result of the field study concerning the best time of P and K fertilizer application for greatest yield. To test the validity of this speculation a study was set up on the field whereby cowpea dry pod weights produced from applying the fertilizer 10, 20, 30, 40 and 50 days after emergence were determined.

Cowpea root length increased exponentially with plant age between 5 and 50 days after emergence, even though the relationship tend to be linear at the very young growth stages. The extent of agreement between root growth on the field and in the greenhouse suggests that solution culture research results could be applied to field conditions. Nutrient flux was greatest when the plant was 5 days old, decreased rapidly with age of the plant to about 28 days old, remained constant for the next few days, then increased again and stayed relatively high between 40 and 50 days.

Dry pod yield obtained by fertilizing cowpea with P and K of 40 days old was significantly greater ($P < 0.5$) than yields from 20, 30 and 50 days application dates, but not significantly superior ($P > 0.5$) to yield from applying fertilizer at 10 days. It is concluded that availability of P and K to cowpea root in the soil is critical to optimum pod yield at the early vegetative growth stage (about 10 days after emergence) and during the early flowering stage, but apparently more critical at the early flowering than the young growth stage.

Introduction

The plant root properties are some of the important parameters which determine the efficiency of utilization of soil phosphorus and potassium (Claassen and Barber, 1976). The amount of applied nutrient absorbed by plant at any given time depends on the physiological capacity of the root to absorb the nutrient and the amount of root growth in the fertilized soil (Nye, 1966; Mengel and Barber, 1974). Therefore, information on root growth and the rate of nutrient uptake per unit of root length, as well as how these change with plant age, should be useful in determining the period of growth during which nutrient supply to the root may be most limiting to nutrient uptake and crop yield. If we know the age at which plant root is most efficient in absorbing nutrients, and also how plant root length or density increases with time in soil, it may be possible to plan fertilization program such that nutrients will be most available at the root surface during the period of greatest root uptake efficiency, thereby increasing the fertilizer use efficiency of the crop.

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Information presently available on the nutrient uptake characteristics of the roots, and the amount and size of roots of tropical grain legumes, such as cowpea (Adepetu and Akapa, 1977; Summerfield and Minchin, 1976) is grossly inadequate for evaluating the levels of available soil nutrients needed at various stages of the plant's growth for optimum yield. The objectives of the present research were (1) to determine the relationships between root length and surface area, and the age of cowpea plant under field conditions; (2) to determine how phosphorus (P) and potassium (K) flux into cowpea roots in the field changes with age of the plant; and (3) to evaluate how variation in nutrient flux and root surface area with plant age affects the critical time of applying P and K fertilizers to cowpea for optimum efficiency of fertilizer utilization.

Materials and methods

Ife brown cultivar of cowpea (**Vigna unguiculata** L. Walp.) was grown on the Egbeda soil series (Oxic Paleustalf) at Ife University research farm. The purpose of the study was to determine the root length, total root surface area, and P and K flux into the roots at varying ages of cowpea under field conditions. Some properties of the soil used in this study are presented in table 1. The plot was divided into four blocks, and the harvesting dates randomised as treatments within each block. There was one cowpea plant per stand. Harvesting was done at five days intervals from day-five to day-fifty after emergence; one plant was harvested per block per sampling date. Both shoots and roots were sampled by excavating a plant in a cylinder of soil 30cm in diameter by 30cm deep. The shoot was cut at soil level, dried at 80°C and weighed. The roots were separated from soil by washing the soil through a 35-mesh plastic sieve, and picking the roots from the sieve with forceps. After washing the roots in distilled water, they were preserved in fresh distilled water containing a few drops of toluene pending length and fresh weight measurements. The root length of the fresh root system was determined by the line intercept method of Newman (1966). Root fresh weight, root and shoot dry weights, and P and K contents of the dry shoot were determined. Because of the over-all exponential nature of the root growth curve for the experimental period, the mean nutrient flux between sampling dates was calculated as earlier done by Adepetu and Barber (1978) using equation 1.

$$\text{Flux per meter of root} = \frac{(U_2-U_1)(\ln L_2-\ln L_1)}{(t_2-t_1)(L_2-L_1)} \qquad (1)$$

where U is the amount of nutrient uptake, t is plant age, L is root length and subscrips refer to successive harvests.

The mean root diameter was determined and total surface area of root system calculated according to Adepetu and Akapa (1977).

Since the earlier study of Adepetu and Akapa (1977) in this Laboratory showed a linear relationship of root growth in nutrient solution and age of young cowpea plants (up to about 25 days age) grown under the greenhouse conditions, it became necessary to conduct a greenhouse solution study with cowpea for days five to fifty after emergence so as to compare the data with root growth curve under field condition. This study was conducted similarly to the earlier one of Adepetu and Akapa except that root sampling was done up to fifty rather than thirty days, and only the "complete" nutrient formulation was used.

From the field data, the curves showing the relationships between nutrient uptake rate per unit root length and plant age was constructed. From the nature of this curve, we speculated on the best growth stage of cowpea to apply P and K fertilizer for maximum utilization. To ascertain the validity of this speculation, a study was conducted with cowpea on the field using the Egbeda soil series. In this study, P & K fertilizers at rates 60kg P/ha. as single super phosphate and 90kg K/ha. as muriate of potash were applied to cowpea plants at the following ages after seedling emergence: 10, 20, 30, 40 and 50 days. There was a control treatment to which no P or K was applied. The study was conducted using a randomized complete block design with four replications. 30kg N/ha. as sulfate of ammonia was applied to all the treatments at 5 days after emergence. The study was conducted during two consecutive seasons. At dry pot stage, the pods were harvested, and dried for unshelled yield determination.

In this study, soil O.M content was determined by a modified Walkley-Black procedure (Smith and Wilden, 1940); available P by Bray number 1 extraction and Murphy and Riley colorimetric method (1962); Exchangeable cations by flame analysis after soil extraction with *IN* Ammonium acetate; Nitrate-N by $CuSO_4$ extraction and phenoldisulfonic acid colorimetry; and soil pH was determined in O.OlM $CaCl_2$ suspension with a Pye Unicam pH-meter.

TABLE 1: SOME PROPERTIES OF THE SOIL USED FOR ROOT GROWTH AND NUTRIENT UPTAKE STUDIES IN THE FIELD

Parameter		Mean value
O.M. (%)		1. 6
pH (O.OlM$CaCl_2$)		6. 1
C.E.C. (Meq./100g)		9.25
Soluble NO_3-N(ppm)		14. 1
Avail - P (ppm)		13. 6
Exch - K (ppm)		160
Exch. Cations (Meq./100g):		
	Na	0.04
	Mg	0.17
	Ca	1.50
Bulk density (g/cm^3)		1.47

Results and discussions

Figure 1 suggests an exponential relationship between the length of the root system and age of cowpea plant, up to 50 days (after emergence) of age, when grown under field conditions. Earlier, Mengel and Barber (1974) had also observed an exponential increase in the amount of corn root present during the vegetative growth stage of the plant; this growth characteristic was attributed to rapid root development accompanied with very few, if any, senescence during this stage of life-cycle. For much younger cowpea plants grown in solution culture in the greenhouse, Adepetu and Akapa (1977) observed a linear root growth relative to the age of the plants. Figure 1 seems to suggest that up to about 25 days after emergence the linear relationship also obtains for the root system of young cowpea plants grown under field conditions.

The apparent agreement between root growth of young cowpea relative to age in solution culture in the greenhouse, and the growth under field condition is interesting in that it suggests applicability of solution studies on root growth characteristic to field situation. For better comparison therefore, a study was conducted in the greenhouse to ascertain if the overall exponential root growth rate observed in the field would obtain in solution culture for comparable ages of cowpea plant. The result presented in figure 2 shows that, similarly to the result obtained in the field, root production rate was exponential with plant age between the

TABLE 2: MEAN ROOT DIAMETER, TOTAL SURFACE AREA OF THE ROOT SYSTEM, AND SHORT DRY WEIGHT AT DIFFERENT AGES OF COWPEA GROWN ON THE FIELD.

Plant age (days)	Mean root diameter (mm)	Total surface area of root system (mm^2/plant)	Shoot dry wt (g/plant)
	0.19	1910	0.08
10	0.18	4287	0.21
15	0.19	6733	0.52
20	0.19	7796	1.04
25	0.19	9347	1.13
30	0.19	14767	1.66
35	0.16	21031	2.43
40	0.24	32587	4.97
45	0.26	43471	11.88
50	0.30	53797	12.41

ages of 5 to 50 days after emergence. However, there was disparity between the greenhouse and the field conditions in the total length of root produced at each growth age. The reduction in root length produced in the solution culture compared to field soil culture probably resulted from higher root-zone temperature and lower light intensity in the greenhouse than in the field. According to Beauchamp and Lathwell (1967), plants grown with higher root-zone temperatures produced lower dry matter. In the present studies, the light intensity was lower in the greenhouse than outside and the temperature was usually greater especially in the afternoons.

Plant age of 50 days was selected in this study as the maximum age of interest because we were concerned with nutrient uptake during the vegetative growth stage when active absorption from soil occur rather than the reproductive stage when nutrient uptake becomes low (Warncke and Barber, 1974). Ajani and Okunade (1978) have shown that the peak flowering activity was reached in Ife brown cultivar of cowpea 43 days after emergence (48 days after planting).

Fig. 1. Relationship between age and root length of cowpea under field conditions

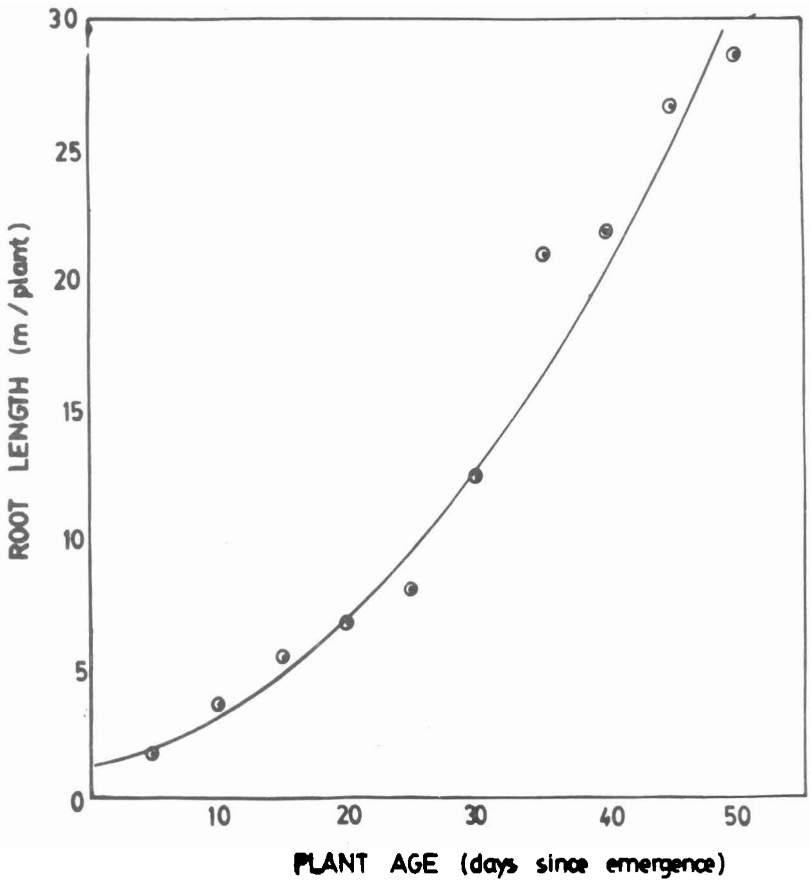


Fig. 2. Relationship between age and root length of cowpea grown in solution culture in the green- house.

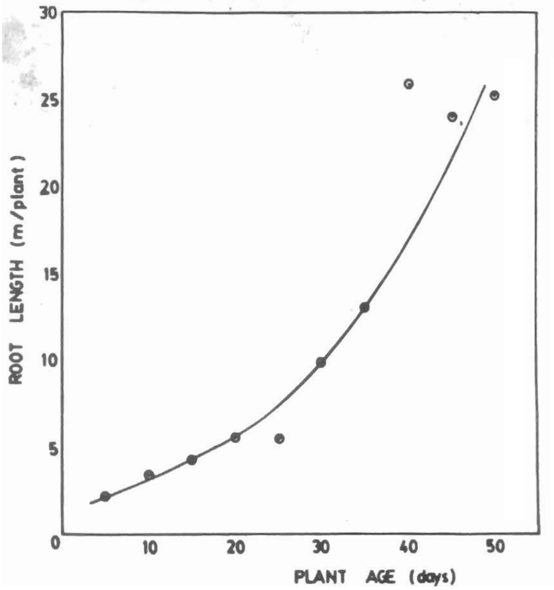
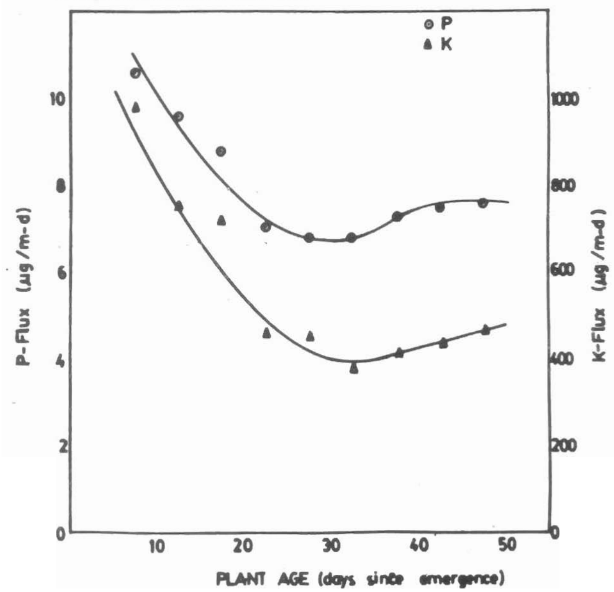


Fig. 3. The relationship between P and K uptake rates per unit root length (flux), and age of cowpea grown on the field.



The nutrient flux into the root was calculated as uptake rate (mg/day) per meter of root length. To minimize variation in weather conditions, uptake rates were calculated at 5 days intervals by averaging the rates over two-and-one-half days before and two-and-one-half days after the indicated age. Hence in making use of equation 1 to calculate uptake rate per unit root length (flux), a constant time interval of 5 days ($t_2 - t_1 = 5$) was used.

The relationship between P and K flux and age of cowpea plant grown under field conditions is shown in figure 3. For both nutrients, the flux was greatest when the plant was young, and decreased rapidly until about 28 days old when the flux became uniform for a few days (about 5 days); but at about 33 days old, the nutrient flux started to increase with age and remained relatively high till the 50 days age studied. Even, then, the results show that cowpea plant roots absorbed P and K more rapidly when the plant was 5 to 15 days old. Mengel and Barber (1974), and Warncke and Barber (1974) have previously observed an uninterrupted decline in the P and K flux to corn root with plant age under both field and greenhouse conditions. For cowpea, the present study seems to indicate that there are two stages of growth when P and K supply to the root would be most limiting: at the young age between 5 and 15 days after emergence; and at a later growth stage, between 35 and 45 days after emergence. The later period of high nutrient demand coincides with a period extending between the beginning and the peak of flowering. The earlier suggestion of Drew *et al* (1968) that root absorption power (α) of a plant specie may change with the physiological age of the plant seemed to be supported by the result of this study. Taking the early flowering period as a preparatory stage of the reproductive phase of the life cycle of cowpea, the sudden upturn in the flux: age curve during early flowering must be a response to increase nutrient demand in preparation for the high nutrient requiring period of seed formation and food storage. It does appear that the physiological changes during transition from vegetative to reproductive phase include an alteration of the root absorption power (α) in this crop. As long as the soil is able to satisfy the plant's demand, uptake increases as root absorption power increases (Nye, 1966). So a change in physiological condition may cause a change in nutrient flux into the root. To facilitate an increase in P and K flux, one or both of the following changes may occur to the root system: (I) some of the older suberized roots may develop a network of interconnecting plasmodesmata in the endodermis. Clarkson *et al* (1971) have shown by electron microscopy that the thickened endodermal wall of barley roots is penetrated by numerous plasmodesmata which may form a pathway for water and ion flow of relatively low resistance. (II) The root system may develop more root hairs, increase the total surface area of roots and therefore increase the capacity of the root to absorb (Lewis and Quirk 1965; Place and Barber 1964, Olsen and Kemper 1968).

The nutrient P and K (native and fertilizer sources) absorbed by the root from soil is a product of the adsorption per unit root surface area and the total root surface area in contact with nutrients. The total root surface area is a function of the root length while the absorption power which may itself be influenced by the physiological demand of the plant for that nutrient. Therefore the method and time of application of fertilizer P and K to soil in order to obtain the greatest efficiency of utilization by the cowpea plant should depend on the rates of uptake as well as the total root surface of the plant. Figure 3 has indicated that the rate of uptake was greatest at the early growth stages of the plant, but table 2 shows that the total surface area of the root system was smallest at those early stages. Hence, predicting the best time of fertilizer application for maximum nutrient utilization, from the nutrient flux data, is not easy especially with cowpea where the decline in nutrient flux with age is not continuous but was interrupted by an increase during the transition period between the vegetative and the reproductive growth phases (Figure 3). Even so, the high nutrient flux of young cowpea plants indicates that a high level of available soil P and K is needed during early plant growth than later in the growth cycle; hence, application of fertilizer P and K may be most critical during the early ages than later.

An investigation was carried out to determine the age of cowpea at which P and K fertilizer application would be most critical for efficient utilization of the nutrients and therefore for seed formation. Table 3 shows the yields obtained by applying P and K fertilizers to cowpea at different indicated ages. Yield was highest when P and K fertilizers were applied 40 days after emergence, followed by yields at 10 days and then yield at 50 days. The yield obtained when fertilized at 40 days was significantly greater ($P < 0.05$) than yields from 20, 30 and 50 days application dates

TABLE 3: YIELD RESPONSE OF COWPEA TO P AND K FERTILIZER APPLIED AT VARYING PLANT AGES AFTER EMERGENCE.

Fertilization: age after emergence (days)	Dry Yield** Per Plot*** (g)
10	358.8 bc
20	301.3 ab
30	307.5 ab
40	431.3 c
50	333.8 ab
Control	226.8 a
Sx	30.3

* Values followed by the same letter are not significantly different at the 0.05 probability level by the DMR test.

** Each yield value is a mean of eight values (4 replicates for 2 seasons).

*** Plot size = 0.0018 ha.

but not significantly superior to the yield from application at 10 days. There were no statistically significant ($P > 0.05$) differences in the yields from applying fertilizer at 10, 20, 30 or 50 days. Surprisingly, yields from 20, 30 and 50 days application dates were not statistically superior ($P > 0.05$) to the yield of the control (no P or K applied).

It will be recalled from Figure 2 that P and K uptake rates per unit length of cowpea root were very high at 10 days and fairly high at 40 days after emergence. The yield result indicates that available P and K supply in the soil is critical to optimal pod yield during these two stages of growth, but apparently more critical at 40 days than 10 days after emergence. Fertilizer supply during the early critical age (around 10 days) may not be available in enough "residual" quantity to meet crop demand during the later critical period (about 40 days) because of P fixation and K leaching. Studies in this Laboratory by Adepetu and Olarewaju (unpublished) have shown that the longer the fertilizer P is made to interact with Nigerian soils, the greater the extent of P fixation by soil and therefore the less the fraction of the applied P available for root absorption. Further studies are suggested to determine if significantly better yield than obtained in this study could be achieved by splitting P and K fertilizer applications into a small dose at about 10 - 15 days after emergence and a larger dose at about 35 - 40 days.

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