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Mineral nutrients uptake and partitioning in *Disocorea alata* and *Dioscora rotundata*

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ABSTRACT

Objective: To describe the N, K, Ca, P and Mg uptake and partitioning into various plant parts for two representative yam species (*D. alata* and *D. rotundata*) under field conditions.
Methodology and results: *D. alata* cv. 90/00010 and *D. rotundata* cv. 89/02461 were grown in a ferralsol in central Côte d'Ivoire in 2003. Shoot and tuber matter production were significantly higher in *D. alata* than in *D. rotundata*. At the whole plant level, uptake of N and K, which were the main nutrients exported by yams, increased rapidly with plant age. Uptake of Ca also increased with plant age but reached a plateau from 103 to 163 days after planting (DAP) and decreased during the rest of the growth cycle. Uptake of Mg and P was low and almost constant during the entire growth period. The amounts of nutrients partitioned into shoot (leaf + vine) increased between 103-140 DAP and decreased to nil between 1 to 2 months later as they were transferred to tuber and lost due to senescence. However, the amount of nutrients stored in tuber steadily increased from tuber initiation (76 to 103 DAP) until harvest time (194 to 220 DAP). At harvest, the amounts of N, K, Ca, Mg and P removed from the soil by *D. alata* tuber were 216, 178, 27, 14, 10 kg/ha respectively, while *D. rotundata* tubers removed 66, 104, 25, 9 and 3 kg/ha of N, K, Ca, Mg and P, respectively.
Conclusions and application of findings: This study has shown that while nutrient uptake and partitioning among the different organs of *D. alata* and *D. rotundata* followed similar patterns, there was a significant difference between both species in terms of the amounts of nutrient taken up. These figures are valuable basis for the development of sustainable and functional mineral fertilization scheme of yams in the study area or elsewhere with similar conditions.
Key words: *Dioscorea alata, Dioscorea rotundata*, Dry matter production, Nutrients uptake and partitioning,

INTRODUCTION

Yams *(Dioscorea spp.)* are tropical tuber crops widely grown in West Africa, Central America, the Caribbean, Pacific Islands and Southeast Asia. In these regions, yams play an important role for food security and have also many other socio-cultural values (Lebot, 2009). This is especially true in West Africa where more than 90% of the worldwide production occurs, estimated at 46 million tons in 2007 (FAO, 2009). Yams are produced by smallholders in shifting agricultural systems without any external inputs. Yields obtained in such systems are of the magnitude of 9-12 metric t/ha of fresh tuber (Ettien, 2003; Gondo, 2003) while the potential yield of the most cultivated species (*D. alata* and *D. rotundata*) are estimated to be in the range of 30-75 t/ha (Zinsou, 1997; Diby *et al*., 2004).

A major constraint limiting productivity of yams in smallholders conditions is low soil fertility (O'Sullivan & Ernest, 2008). Yams are known to be demanding in terms of soil fertility, thus in traditional yam-based cropping systems, they are grown first after opening up new land from virgin vegetation or after long term (10-20 years) fallow (Carsky, 2001). However, due to population pressure on land, long-term fallow or virgin vegetation is becoming scanty in West Africa. Besides, because of this annual search for new lands, yam production is considered as one of the major causes of deforestation (Dumont & Vernier, 1997). Hence research for sustainable yam production systems that enhance productivity with moderate impact on the environment is needed in West African smallholders' conditions.

Various studies have attempted to improve yam yields through mineral fertilization in different locations but the results have been variable, with some authors reporting no response to applied fertilizer (Sotomayor-Ramirez *et al*., 2003; Baimey, 2005), while others reported significant response to mineral fertilization under field conditions (Diby *et al*., 2004; Ettien *et al*., 2009). This variable response is not well understood and limited knowledge exists on basic information such as nutrient uptake patterns of the two main yam species (*D. alata* and *D. rotundata*) grown under field conditions.

Thus, undertook a field experiment to determine the amounts and patterns of nutrients uptake and partitioning during the growth period of a *D. alata* and a *D rotundata* species.

MATERIALS AND METHODS

The field experiments were conducted from May to December in 2003 at the field station of the Swiss Centre for Scientific Research (CSRS), near the village of Bringakro in central Côte d'Ivoire. The area is located at the borderline of two agro ecological zones: the Guinea savannah in the north and the tropical moist forest in the south. The experiment was set up in a ferralsol with the soil properties as reported previously (Diby et al., (2004).

The cultivars TDa95/00010 and TDr89/02461, belonging to the species *D. alata* and *D. Rotundata,* respectively, were grown in a randomized complete block design with four replicates. All plants were fertilized with a dose of 240 kg/ha of N, 11 kg/ha of P, 269 kg/ha of K, 8.5 kg/ha of Ca, 11 kg/ha of Mg and 66 kg/ha of S (Diby *et al*, 2009) to ensure an optimal growth. Yam setts were planted on 7th May and the final harvest was done on 17th November for *D. rotundata* and on 13th December for *D. alata*. Three adjacent plants per plot were destructively sampled at shoot emergence (51 days after planting (DAP)), at tuber initiation (76 DAP), during the maximum growth of the above-ground organs (103 DAP), during the rapid growth of the tubers (140 DAP for *D. alata* and 103 DAP for *D. rotundata*), during tuber maturation phase (163 DAP), and at harvest (194 DAP for *D. rotundata* and 220 DAP for *D. alata)*.

At each sampling date, plants were separated into leaf, vine, root and tuber and the fresh weight of each organ was recorded. A sub-sample from each plant part was selected, cut into small pieces and oven-dried at 70°C to constant weight for dry matter determination. For each organ, the N, P, K, Ca and Mg contents was analyzed. Nitrogen concentration was measured with a carbon nitrogen analyzer, while P, K, Ca and Mg concentration was measured with an ICP-OES after incinerating the leaves at 550°C for 6 hours and solubilizing the ashes in concentrated HNO_3.

Data analyses including means and standard errors calculation and analysis of variance were performed using SAS 8.1

RESULTS AND DISCUSSION

Dry matter production: Dry matter accumulation and partitioning in different plant organs showed similar patterns in both *D. alata* and *D. rotundata*. Leaf and vine dry weights increased from emergence and reached their maximum values between 103-140 DAP, followed by a decline phase which continued until harvest due to leaf and vine senescence (Figure 1). The maximum shoot (leaf + vine) dry weight of *D. alata* (3.4 t/ha) was reached at 140 DAP, while that of *D. rotundata* (1.3 t/ha) was reached at 103 DAP. Both fine and coarse roots dry weight was consistently low (< 0.1 t/ha) during the overall growth season in both species.

Tuber dry weight of *D. alata* increased consistently from tuber initiation (103 DAP) to harvest. In *D. rotundata*, tuber dry weight also increased from tuber initiation (76 DAP) up to 163 DAP and levelled off thereafter (Figure 1). The dry matter accumulation and partitioning pattern observed in this study followed the general pattern already reported previously (Goenaga & Irrizary, 1994; Roy, 1998). The proportion of dry matter accumulated in tuber at full maturity of the crop was similar in both species. Tuber dry weight of *D. alata* (10 t/ha) accounted for 92% of the total dry weight and that of *D rotundata* (4 t/ha) accounted for 94% of the total dry weight.

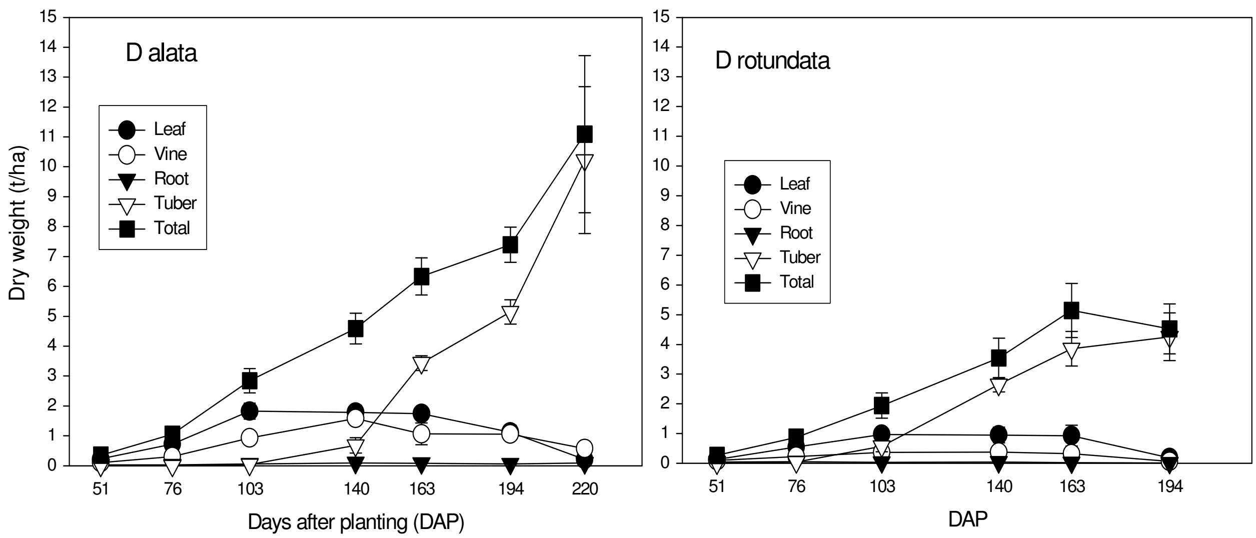

Figure 1: Total dry matter and dry matter accumulation pattern in leaf, vine, root and tuber of yam (*Dioscorea* spp.) grown in central Côte d'Ivoire in 2003. Error bars represent the standard error of the mean for each sampling date.

Nutrient content: The general trends of nutrients contents in the whole plant followed similar patterns in both *D. alata* and *D. rotundata*. N levels increased globally with plant age up to 103 DAP and decreased slightly thereafter while that of K followed a consistent increase phase over the growing season (figure 2). The higher content of N in the plant early in the growth season could be explained by an active N uptake from the soil to support aboveground biomass production, while the decrease of N with plant age may be associated with the loss of structural N through senesced leaf. The progressive increase of K in the whole plant during the growing season confirmed its important role in the transfer of assimilates to the tuber (Marschner, 1995). Indeed, K level increase with tuber initiation and sustains tuber growth over the season (Enyi, 1972). Magnesium and P contents increased slightly with plant age while Ca content increased up to a maximum (reached at 140 DAP) and decreased thereafter. Both Mg and P concentrations were very low (< 5 mg/g biomass) during the entire growth period.

Nutrient uptake and partitioning in plant parts: The general patterns of nutrients uptake by *D. alata* and *Ds. rotundata* plants investigated in this study were similar. Potassium and nitrogen consistently increased over the growing season at the whole plant level (figure 3). At harvest, the total amount of N taken up was 229 kg/ha in *D. alata* and 70 kg/ha in *D. rotundata*. In both species, 94% of the total amount of the N was accumulated in the tubers. The potassium uptake at harvest was 196 kg/ha and 110 kg/ha in *D. alata* and *D. Rotundata*, respectively, of which 91% was accumulated in *D. alata* tuber and 94% in *D. rotundata* tubers.

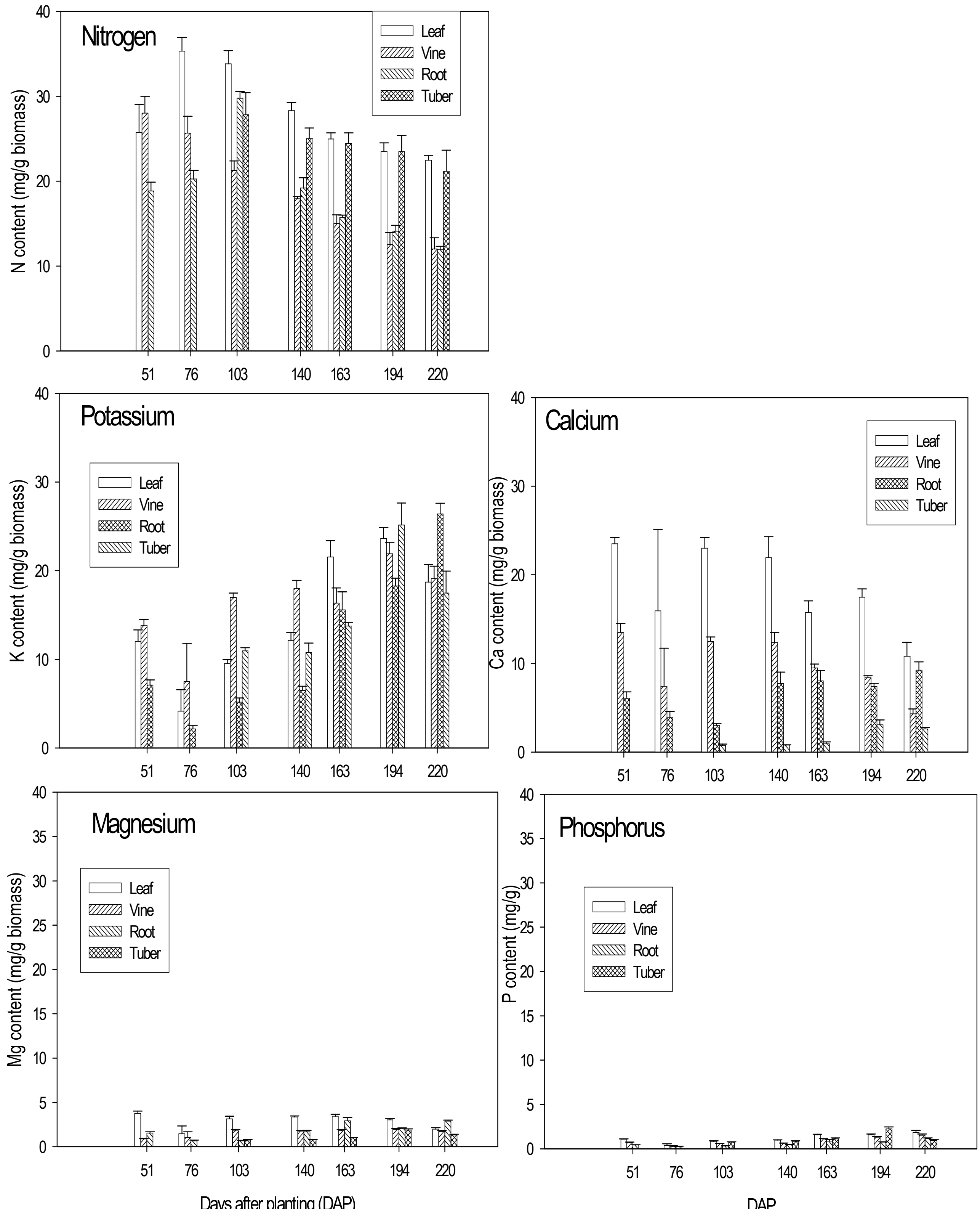

Figure 2: Nutrients contents in plant parts of *D alata* grown at a forest site in central Côte d'Ivoire in 2003. Similar pattern were found in *D. roundata*. Error bars represent the standard error of the mean for each sampling date.

These figures showed that at harvest, the highest (91-94%) proportion of the total N and K were accumulated in tuber which acted as a sink for these nutrients. As a consequence, only a small proportion of the N and K taken up returned to the soil as dead organic matter, which explains the common observation that *Dioscorea* spp deplete soils, and that N and K are the most demanded nutrients for yams growth (Degras, 1993; O'Sullivan, 2008). This may also partly explain why in traditional cropping systems, yams are grown first after opening-up long term fallow (Carsky *et al*., 2001) where soil fertility has been restored.

In contrast to N and K, P and Mg showed only a small increase and remained very low in both species over the growing season. Phosphorus and magnesium peaked at 163 DAP and 194 DAP in *D. alata* and *D. Rotundata,* respectively. At these dates, P accounted for 15 and 4 t/ha in *D. alata* (figure 3) and *D. rotundata* (figure 4), respectively; *D. alata* accumulated 78% of the P uptake in tuber compared to 50% for *D. rotundata*. On the other hand, magnesium accounted for 15 and 13 t/ha in *D. alata* and *D. rotundata* of which 63 and 74% was in tuber of the two species, respectively.

These observations suggest that P and Mg were less depleted from soil by yam tuber compared to N and K; and that *D. alata* exports more P from the soil than *D. Rotundata.* This difference in P and Mg uptake between the two species has not been illustrated earlier under controlled or field experiments, and clearly the physiological basis explaining such difference warrants further investigation. The low uptake of Mg and P does not imply that these nutrients are deficient in the growing site since soil analysis did not show any Mg or P limitations for yams growth (Diby *et al*., 2004). This suggests, however, that these two yam species are not too demanding for Mg and P. The low uptake of P and Mg by *Dioscorea* species has already been reported from both field and pot experiments (Obigbesan & Agboola, 1978; Diby, 2005; O'Sullivan & Jenner, 2006; O'Sullivan & Ernest, 2007).

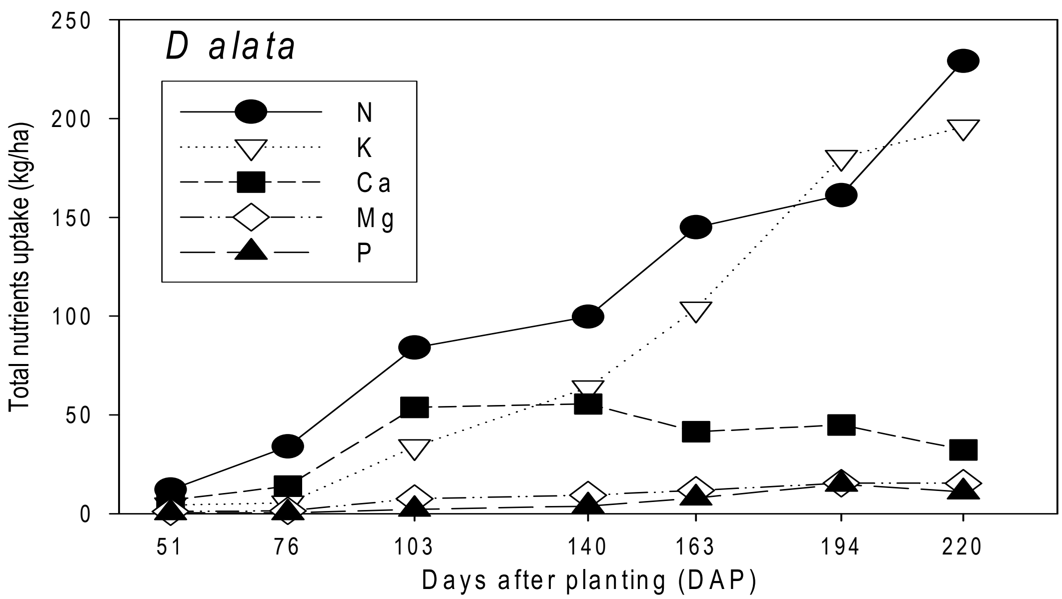

Figure 3: Total nutrients exported by *Dioscorea alata* grown in a ferralsol in central Côte d'Ivoire. Similar pattern was observed for *D. rotundata.*

Calcium uptake increased from planting up to a peak which coincided with the active growth period of the shoot (reached at 140 DAP for *D. alata* and 103 DAP for *D. rotundata*) and declined thereafter. The amount of Ca taken up at this growth period was 55 and 22 t/ha in *D. alata* and *D. rotundata*, respectively. Only 1 and 8% of these amounts of Ca was accumulated in tuber in *D. alata* and *D. rotundata*, respectively (figures 3 and 4). The remaining Ca was mainly accumulated in leaf and vine which had up to 98 and 92% of the Ca in *D. alata* and *D. Rotundata,* respectively.

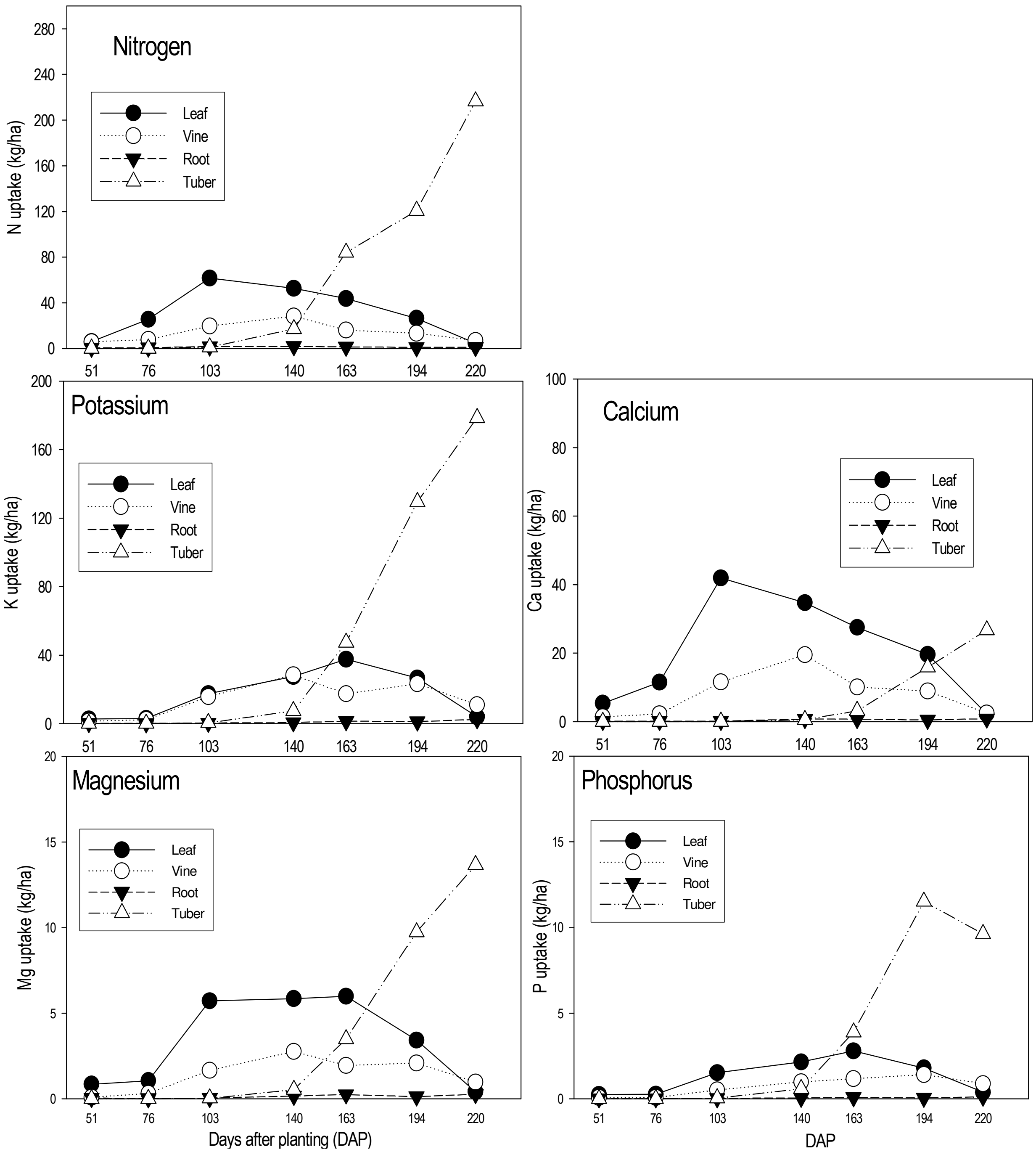

Figure 4: Nutrients uptake by *Dioscorea alata* over the growing season in Cote d'ivoire.

At harvest, the total amounts of Ca in the shoot of both species declined and its proportion in tuber increased to 83 and 93% for *D. alata* and *D. Rotundata*, respectively, because at this stage the main sinks for Ca (leaf and vine) were mostly senesced. The amount of Ca stored in tubers of both species at harvest was about twice lower than the amount of Ca present in the whole plant at the maximum growth phase, suggesting that a large proportion of Ca was apparently returned to the soil with senesced leaves. On the other hand, all the other nutrients (N, K, P and Mg) stored in tuber at harvest were larger than the amounts of these nutrients present in the entire plant at the maximum growth phase. This could be explained by the fact that a major fraction of these nutrients mainly located in the leaves and vines were transferred to tuber prior to their death, and that the plant continued to take up these nutrients until late in the growth cycle.

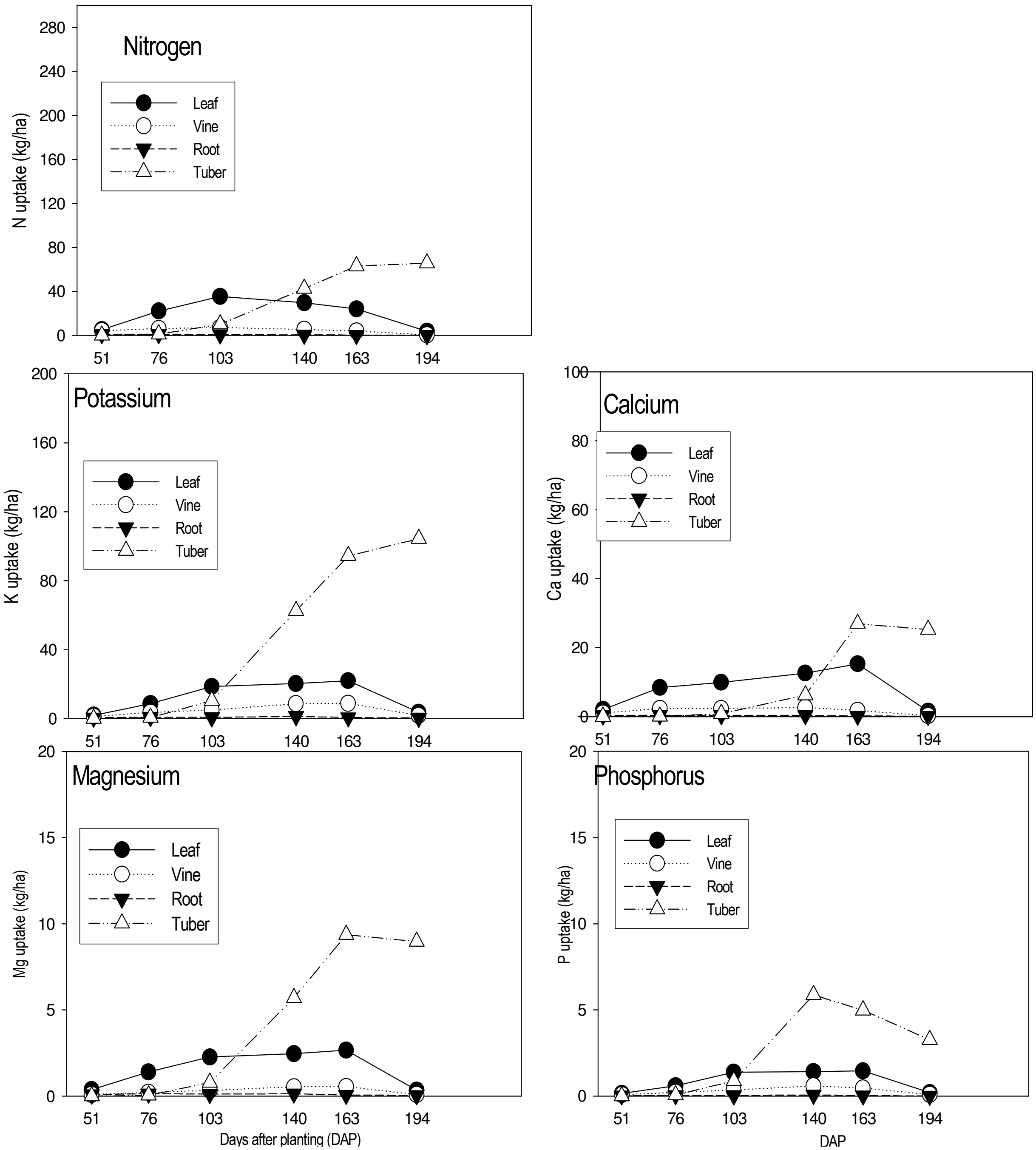

Figure 5: Nutrients uptake by *Dioscorea rotundata* over the growing season in Cote d'Ivoire.

Changes in nutrients uptake were observed in both species between different plant parts over the growing season. The amounts of nutrients taken up were about five times lower in *D. rotundata* when compared to *D. alata* suggesting a more efficient nutrient uptake and recycling capacity of the latter species. Similar results were observed by Obigbesan and Agboola (1978) who worked with two cultivar of *D. rotundata* and one cultivar of *D. alata*. This higher nutrient uptake by *D. alata* resulted in higher fresh tuber production which is the harvested product of edible *Dioscorea* spp. Indeed, the yield of *D alata* obtained in this study was 50 t/ha whereas that of *D. rotundata* was 10 t/ha.

This study has shown that nutrient uptake and partitioning among the different organs of the yam plant depends on the species, the type of nutrients and the growth period in the season. These results are valuable for the development of an integrated soil fertility management and sustainable yam production systems.

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