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Yams (*Dioscorea* spp.) plant size hierarchy and yield variability: Emergence time is critical

D. Cornet[a,b,*,1], J. Sierra[c], R. Tournebize[c], B. Ney[d]

[a] CIRAD, UMR AGAP, F-97170 Petit-Bourg, Guadeloupe
[b] IITA-Benin, BP 08-0932 Cotonou, Benin
[c] INRA, UR1321 ASTRO, Agrosystèmes Tropicaux, F-97170 Petit-Bourg, Guadeloupe
[d] AgroParisTech, UMR1091 INRA AgroParisTech, F-78850 Thiverval-Grignon, France

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ABSTRACT

Yam crops (*Dioscorea* spp.) present a very high and unexplained interplant variability which hinders attempts at intensification. This paper aims to characterize the plant-to-plant variability in yield and to identify its underlying causes for the two major yam species (*Dioscorea alata* and *Dioscorea rotundata*). Four field experiments were carried out between 2006 and 2009 in Benin. Yams were grown using a traditional cropping method (i.e. in mounds at 0.7 plants m^{-2}) without biotic or abiotic stresses. In order to test interplant competition, a low density treatment (0.08 plants m^{-2}) was included for *D. alata* in the 2006 experiment. Throughout four years of experimentation, yields varied from 12 Mg ha^{-1} to 21 Mg ha^{-1}. Both yam species presented a high interplant coefficient of variation (CV) for tuber yield (42–71%). The unbiased Gini coefficient (G') was used to measure how steep a hierarchy is in an absolute sense. CV and G' of individual plant biomass both confirm clear plant size hierarchies from early growth. However, no difference in the CV of plant size and plant tuber yield was observed between high and low plant density. This implies that, despite early interaction between neighbouring plants, competition was not the driving factor controlling plant variability. In fact uneven emergence proved to be the primary cause. Yam emergence takes place over a long period (e.g. it took 51 and 47 days for the 90% central range to emerge for *D. alata* and *D. rotundata*, respectively), creating an early inter-plant size hierarchy which later affected tuber production. For both species, plants which emerged early initiated their tuberization earlier in the growing season and reached higher maximum yield regardless of weather conditions (e.g. 1200 and 764 g $plant^{-1}$ for early-emerging *D. alata* and *D. rotundata* plants respectively, and 539 and 281 g $plant^{-1}$ for late-emerging plants). Plant size hierarchization together with its observed left-skewed distribution, led to reduce total and marketable yield by increasing the proportion of small tubers. These results highlight the need to better understand the underlying mechanisms controlling the yams' uneven emergence before attempting to improve traditional cropping systems.

1. Introduction

Dioscorea is a C3 monocotyledonous genus grown throughout the tropical world for food, pharmaceutical products, and ornamental purposes (Ayensu, 1972; Cornet et al., 2007). It is an important food crop in at least ten tropical countries from Nigeria to Jamaica and the Solomon islands, accounting for 155 million inhabitants. More than 85% of world yam production takes place in West Africa (FAOSTAT, 2012). Despite its economic value, only limited literature is available on the physiology of the crop and on the effect of agricultural practices on yields (Onwueme and Haverkort, 1991). This is particularly important because of the tremendous yield gap (Nin-Pratt et al., 2011) and the wide range of crop management practices applied to yams; e.g. staked or non-staked,

Abbreviations: CV, coefficient of variation; DAE, number of days after 50% emergence; G, Gini coefficient; G′, unbiased Gini coefficient; P0–20, first 20 percentile; P20–40, 20th–40th percentile; P40–60, 40th–60th percentile; P60–80, 60th–80th percentile; P80–100, last 20 percentile; S, Lorenz asymmetry coefficient.

* Corresponding author. Present address: CIRAD, UMR AGAP, F-97170 Petit-Bourg, Guadeloupe. Tel.: +590 590 255975; fax: +590 590 259416.

E-mail addresses: denis.cornet@cirad.fr, denis.cornet@antilles.inra.fr (D. Cornet), jorge.sierra@antilles.inra.fr (J. Sierra), regis.tournebize@antilles.inra.fr (R. Tournebize), bertrand.ney@agroparistech.fr (B. Ney).

[1] Present address: CIRAD, UMR AGAP, Petit-Bourg, F-97170, Guadeloupe, France. INRA, UR1321 ASTRO, Petit-Bourg, F-97170, Guadeloupe, France.

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multiplication by sets of various size and origins, and varying fertilizer rates and planting dates (Orkwor et al., 1998).

Attempts to better understand yam crop physiology and reduce yield gap come up against the very high and still unexplained intra-field yield variability (Akoroda, 1984; Ferguson et al., 1969; Okoli et al., 1999). Coefficient of variation (CV) of individual plant yield is often used to estimate this variability (Weiner and Solbrig, 1984). While plant yield CV reported in the literature for potato (*Solanum tuberosum* L.) or sweet potato (*Ipomea batatas* L.) hardly reached 30%, yams have a CV as high as 60% (Akoroda, 1984; Alcoy et al., 1993; Okoli et al., 1999; Wurr et al., 1993). Consequences of this plant-to-plant yield variability are already known for other root and tuber crops: (i) lower mean yield, (ii) lower marketable production due to tiny and oversized tubers, and (iii) difficulties for intensifying cropping systems because of the high variability of the individual's response to agronomic practices (Alcoy et al., 1993; Mackerron et al., 1988).

Beneath an apparently uniform cover, yam fields contain individual plants of variable size. In fact, most plant populations exist as size hierarchies of individuals (Weiner and Thomas, 1986). The size hierarchy refer to the frequency distribution of individual plant sizes in which relatively few individuals contribute most of the population's biomass and most individuals are relatively small. These unequal distributions are appropriately thought of as size (usually biomass) inequalities (Weiner and Thomas, 1986). In controlled environment and monospecific stand, Weiner and Thomas (1986) identified two main factors driving strong individual size hierarchies. First, they showed that these size distributions could be a direct consequence of interplant competition. Here competition refers to the negative effects caused by the presence of neighbours by reducing the availability of resources (Harper, 1977). Furthermore, Weiner and Thomas (1986) demonstrate the existence of a positive relationship between size inequality and population density as a consequence of increasing interplant competition with increasing plant density. However interplant competition might be limited in the traditional cropping systems of West African farmers because of the low yams planting density.

The second factor driving strong individual size hierarchies highlighted by Weiner and Thomas (1986) is the uneven emergence, leading to plant age differences (Black and Wilkinson, 1963; Damgaard and Weiner, 2000). Unlike potatoes, yams do not benefit from a well-structured certified tuber seed production system allowing fast and uniform sprouting. Because yams are grown by planting pieces of tuber, or small whole tubers (called seed yams) saved from the previous season, many factors may affect emergence. Accordingly uncontrolled seed yam physiological age, size and tuber portion origin (proximal, middle or distal) may influence emergence time (Orkwor et al., 1998) while seed quality (e.g. dry matter and nutrient content) may affect sprouting vigour (Ferguson, 1973; Orkwor et al., 1998). These uncontrolled conditions may lead to a population with disparate plant ages. Hence we hypothesize that for West African conditions yam yield variability in the field is rather a direct consequence of individual emergence variability but not an effect of interplant competition.

The objective of this study was to test that hypothesis. The aims were to assess plant-to-plant yield variability for the two major yam species (*Dioscorea alata* L. and *Dioscorea rotundata* Benth.), and to identify the underlying mechanisms controlling it in the field (emergence and competition). The consequences of these findings are discussed in terms of further improvement of yam cropping systems.

2. Materials and methods

2.1. Experimental site

The data used in this study come from four trials carried out at AfricaRice/IITA-Cotonou Station (Benin, 6°25 N, 2°19 E, 23 m asl) between 2006 and 2009, using the two main yam species *D. alata* and *D. rotundata*. For *D. rotundata* the cultivar Morokorou was used. It is a traditional early-maturing variety originating from north Benin, producing a few (1–3) cylindrical tubers. For *D. alata* the cultivar Florido was used. It was introduced into West Africa from Puerto Rico in the early 1970s and produces two to five round tubers (Doumbia et al., 2004).

The soils used in this study are arenosols (FAO-ISRIC-ISSS, 1998) with good physical characteristics but low nutrient levels (Table 1). The field experiments were located in the forest-savannah transition zone. The climate is sub-equatorial with a bimodal rainfall pattern and a mean annual rainfall of 1200 mm, falling mainly during the rainy seasons from March to July and from September to October. The mean annual temperature was about 27 °C with a low diurnal variation of 7–10 °C. All trials followed traditional planting systems used in West Africa. Small entire seed tubers with a constant weight of 400 g were planted without staking in mounds at a density of 0.7 plant m^{-2}. In order to test interplant competition a low density treatment of 0.08 plant m^{-2} was added for *D. alata* in the 2006 experiment. And to completely avoid competition in this treatment, plants were staked and a rope network allowed each stem to grow individually without any plant interaction.

Compound fertilizer was applied at a rate of 60 kg N ha^{-1}, 30 kg P ha^{-1} and 140 kg K ha^{-1} one month after emergence. Additional N was applied two months after emergence as urea at a rate of 60 kg N ha^{-1}. The crop was irrigated to field capacity at planting. Afterward it was irrigated according to a water balance, and further supplementary irrigation (totaling between 80 and 150 mm depending on the cropping season) was applied to replace estimated evapotranspiration using overhead sprinklers (Marcos et al., 2009). The plants did not show any visual evidence of water stress or nutritional imbalance. Weed control was done by hand approximately every two weeks. All experiments were completely randomized design (the yam species being the only factor with two level: *D. rotundata* and *D. alata*) using four replications of 25 plants per treatment.

Table 1
Trials soil characteristics.

Year	Trial	pH	Organic		Available P ($\mu g\,g^{-1}$)	Sand (%)	Clay (%)	Exchangeable					CEC
			C (%)	N (%)				Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	K (cmol kg^{-1})	Na (cmol kg^{-1})	Acidity (cmol kg^{-1})	
2006	T1	4.7	0.5	0.05	8	72	20	1.0	0.5	0.1	0.6	0.3	2.5
2007	T2	4.7	0.8	0.06	22	80	16	1.2	0.5	0.1	0.6	0.4	2.9
2008	T3	4.4	0.6	0.05	9	82	14	0.7	0.3	0.2	0.8	0.2	2.1
2009	T4	4.7	0.7	0.06	7	82	14	0.6	0.4	0.2	0.9	0.3	2.4