South African Journal of Botany 113 (2017) 192–199

Contents lists available at ScienceDirect

South African Journal of Botany

journal homepage: www.elsevier.com/locate/sajb

Characterizing the diversity of sweetpotato through growth parameters and leaf traits: Precocity and light use efficiency as important ordination factors

D.A. Ramírez [a,b,c,*], C. Gavilán [a,1], C. Barreda [a], B. Condori [d], G. Rossel [a], R.O.M. Mwanga [a], M. Andrade [a], P. Monneveux [a], N.L. Anglin [a], D. Ellis [a], R. Quiroz [a]

[a] International Potato Center (CIP), Apartado 1558, Lima 12, Peru
[b] Universidad Nacional Agraria La Molina, Av. La Molina s/n, Lima 12, Peru
[c] Gansu Key Laboratories of Arid and Crop Science, Crop Genetic and Germplasm Enhancement, Agronomy College, Gansu Agricultural University, Lanzhou 730070, China
[d] Adaptive Cropping Systems Laboratory, USDA-ARS, Beltsville, MD 20705-2350, USA

ARTICLE INFO

Article history:
Received 29 June 2017
Received in revised form 2 August 2017
Accepted 21 August 2017
Available online xxxx

Edited by J Van Staden

Keywords:
Crop growth model
DArT
Early-maturing
Ipomoea batatas
Leaf traits
Light conversion efficiency

ABSTRACT

Due to its low-input requirements, high yield capacity in marginal soils, and high carbohydrate and vitamin A content, sweetpotato is an important food security crop. For effective breeding strategies, knowing and understanding the traits that drive diversity among varieties is required. In this study, a set representing the diversity of sweetpotato varieties was characterized through multivariate ordination based on growth parameters and physiological leaf traits. The dynamic of light interception, light use efficiency (LUE) parameters, and partition of assimilates to the storage roots of eight representative varieties were simulated through a crop growth model. Leaf mass per area (LMA), N and P content in leaves, light response curve parameters and carbon discrimination were assessed in potted plants at early-growing period (58 days after planting). Precocity proxies (inversely related to LMA and thermal time at maximum storage root growth) and conversion efficiency of intercepted radiation indicators (quantum yield and LUE) were important factors in the varieties ordination based on leaf traits and growth parameter scales, respectively. Leaf traits assessment at early stages could be used as a starting point for the screening of potential lines, which once identified can be further characterized using crop growth models.

1. Introduction

Sweetpotato (*Ipomoea batatas* (L.) Lam.) is an important tropical and subtropical root crop whose advantages - e.g. low cost of production due to its adaptability and low inputs requirements, high potential productivity and nutritional quality - are important for agriculture and nutrition in developing countries (Mekonen et al., 2015). The high genetic diversity of sweetpotato (8573 accessions including breeding lines, improved varieties, landraces, and wild specimens in store at the International Potato Center Gene Bank, D. Ellis pers. comm.) is congruent with a high diversity of nutritional composition and contents and potential of utilization as a food and feed crop (Mukhopadhyay et al., 2011). Varietal differences are also reflected in the diversity of leaf morphology, root system architecture, time to maturity, disease resistance, and different environmental requirements (Woolfe, 1992). Sweetpotato is chiefly used for human consumption (IFPRI, 2014), particularly in African countries which accounted for 21.2% of the world production in 2014 (FAO, 2017). Despite the high potential productivity, the yield of this crop in Africa has hovered around 5 Mg ha^{-1} for the three past decades and has even shown a slight downward trend over the last several years (IFPRI, 2014). Efforts have been made to identify key traits related to yield through morphological and agronomic characterization of sweetpotato diversity in Africa (e.g. Afuape et al., 2011; Fongod et al., 2012; Maquia et al., 2013); however, additional studies are needed to understand the agro-physiological properties that limit yield.

Thus far, little is known quantitatively about the physiological processes that limit the formation of harvestable roots in sweetpotato (Raymundo et al., 2014). One approach to understand variety-environment interactions in root yield is through growth analysis and modeling (Jame and Cutforth, 1996). A key approach for understanding crop diversity and environment interactions is through the use of light interception and utilization models (Spitters, 1988). The SOLANUM model (Condori et al., 2010) a member of this family of models, has a high prediction power in comparison with other complex models in

---

* Corresponding author at: International Potato Center (CIP), Apartado 1558, Lima 12, Peru.

E-mail address: d.ramirez@cgiar.org (D.A. Ramírez).

[1] Present address: Soil and Water Science Department, University of Florida, P.O. Box 110290, Gainesville, FL 32611-0290, USA.

http://dx.doi.org/10.1016/j.sajb.2017.08.009

crops with below ground storage organs (Quiroz et al., 2017). Some of these modeled growth parameters are related to light use efficiency, precocity and light interception (see Condori et al., 2010; Quiroz et al., 2017). These parameters reflect an integrative environmental response which can be used to characterize the diversity of sweetpotato. On the other hand, functional groups in plant science is assessed through leaf traits related to the so-called "leaf economics spectrum" (Wright et al., 2004) which combine different leaf traits to discriminate precocious from late-maturing species. Thus, leaf mass per area (associated with a broad ecological response, see Poorter et al., 2009), net photosynthesis at light saturation, dark respiration and N and P content are part of the "leaf economic spectrum" which have been used to classify plant diversity in different ecosystems (Wright et al., 2004). The adaptation to different ecosystems and the crop domestication process have both promoted a high morpho-functional diversity in plants, which is evident in sweetpotato. We hypothesize a coherent and complementary relationship between ordination of the varieties based on integrative growth parameters and leaf traits. Some integrative leaf traits related to "leaf economic spectrum", photosynthetic capacity and light response curves were measured at growth potential conditions. Concomitantly, growth parameters similar to those defined for potato in SOLANUM were estimated and used for the analysis. This study was carried out in eight sweetpotato varieties identified from a previous study of genetic diversity using diversity arrays technology (DArT) markers (Rossel et al., 2009). The objective of the present study was to assess the main factors that explain the functional diversity of some representative sweepotato genotypes through a multivariate ordination determined by leaf traits and growth parameters.

2. Materials and methods

2.1. Plant material selection

A subset of sweetpotato accessions from the International Potato Center (CIP) genebank was genotyped using 1088 DArT markers and a diversity cluster was determined using the Dice coefficient and weighted neighbor-joining (Rossel et al., 2009). Five varieties belonging to three contrasting sub-clusters (Zapallo [CIP 420027], Jewel [CIP 440031], Naveto [CIP 440131], Tanzania [CIP 440166], Kakamega [SPK004; CIP 441768]) were selected and completed with Mugande [CIP 440163], Ejumula [CIP 443750] and Nyawo as local materials to be used in the present study (see 2.2.1). Most of these varieties are widely adapted in Kenya and other African countries, others like Kakamega and Ejumula are the important orange–fleshed varieties released in Africa by CIP (Mwanga et al., 2007).

2.2. Growth analysis

2.2.1. Experimental site

The experiment was carried out at the Kiboko Crop Research Station (a Kenyan Agricultural Research Institute facility) located in the Makindu District, Makueni County, Eastern Kenya (2°25′ S, 37°75′ E, 975 m.a.s.l.), approximately 155 km South East of Nairobi. The soil in the trial was sandy clay loam containing 0.5% organic matter and a pH of 8.2. The study area is a hot dry region with a mean annual temperature of 22.6°C and a mean annual rainfall of 600 mm (based on over 70 years of data from Makindu Meteorological Station) (PANESA, 1988).

2.2.2. Experimental design, management and data collection

A split plot in time design with four replications was used. Varieties were randomly assigned to plots of 56 m^2 in size. Sequential harvests taken over time constituted the sub-plots. On 7th May, 2010 sweetpotato vine cuttings (~0.3 m length) were planted at 1 m and 0.3 m of distance within row - on ridges - and cuttings, respectively. N, P, and K fertilizers were supplied at a dose of 100 kg N, 50 kg P_2O_5 and 80 kg K_2O per hectare. Half of the N and K_2O and full P_2O_5 were applied at planting and the remaining half was added as a top dressing 45 days after planting (DAP). The crop was irrigated at 4-day intervals using a 3 m × 3 m grid overhead sprinkler system with two portable main sprinkler lines during the first month after transplanting. Thereafter, the plots were irrigated on a weekly basis, until the maximum canopy cover (80 DAP) was reached after which irrigation intervals were stretched out to about two week intervals until the end of the growing season. Synthetic pyrethroid Lorsban (Chlorpyrifos) was used to protect the plants against sweetpotato weevil, *Cylas formicarius* (F.). No other pests or diseases were observed.

During the growing season, eight sequential harvests were performed at approximately 15-day intervals. Each sample consisted of four adjacent plants taken from one row of each plot in a random replicated manner. Plants were entirely removed from the soil and separated into leaves, stems, and storage roots prior to weighing. Total fresh weight was determined for each organ, and the dry matter fraction was estimated from oven-dried samples (48–72 h at 80°C). The final harvest of the central rows of the plot was done at 123 DAP. The canopy cover was measured with imagery at the same intervals as the biomass determinations; the process used is described in detail in the potato experimental data collecting protocol (CIP, 2013). Minimum and maximum temperatures as well as precipitation and solar radiation were recorded at one-hour intervals by a portable weather station (HOBO Weather Station, ONSET Computer Corporation, USA) located in the field. The daily average photosynthetically active radiation (PAR) was calculated as half of the global solar radiation.

2.2.3. Growth model parameters

The SOLANUM growth model was adapted to simulate the daily accumulation of dry matter and the proportion partitioned to the sweet potato storage roots (Condori et al., 2010; Quiroz et al., 2017). The model (summarized in Table 1) uses eight parameters that describe the principal plant processes involved in the interception of light, the light use efficiency and the partition of assimilates to the storage organs (see Condori et al., 2010 for further details). The crop development processes were described as a function of thermal time (°C days) (see Table 1), considering three cardinal temperatures (base, optimal and maximal) that define the development rate in sweetpotato (12, 23 and 40°C, respectively; Erpen et al., 2013). The light interception parameters: maximum fraction achieved by the canopy cover (MF), rate of relative increase of light interception (R_o) and the initial fraction of light interception at emergence (F_o) were estimated by fitting data of canopy cover to a logistic function through a nonlinear regression based on measured data using SAS v. 9.2 software (SAS Institute Inc. Cary, NC). Partitioning to storage roots, defined as the ratio of dry matter of storage roots over the total dry matter, were represented using three parameters: the maximum fraction partitioned to roots (M), thermal time at maximum storage root growth or at the inflexion point (A, a surrogate of precocity with negative relationship) and the slope on the inflection point (b, a surrogate of maximum root bulking rate). These parameters were calculated by fitting a logistic function using nonlinear regression procedure in SAS v 9.2 software (SAS Institute Inc. Cary, NC). The average light use efficiency (LUE) was determined as the slope of the linear regression between the total dry matter and cumulative intercepted PAR. The percentage of root dry matter (DM_c), was calculated at harvest on a sample of 8 plants per variety.

2.3. Leaf traits assessment at potential early-growing stage

2.3.1. Potted plants

Ten vine cuttings from the CIP germplasm sweetpotato collection (except Ejumula and Nyawo which were not available) were transplanted to peat pellets (Jiffy Products Ltd., Canada) on 11th July 2016 at CIP-La Molina experimental station (12.1° S, 77.0° W, 244 m.a.s.l.) in Lima-Peru. Vine cuttings were irrigated with a 5 mL/L of a root promoting solution (Root-hor®, Comercial Andina Industrial