Agricultural Systems 159 (2018) 50–56

Contents lists available at ScienceDirect

Agricultural Systems

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

Designing new management sequences for pineapple production using the SIMPIÑA model

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A R T I C L E I N F O

Keywords:
Crop model
Optimization
Farm type
Multi-criteria assessment
Ananas comosus (L.) Merr
Reunion Island

A B S T R A C T

The pineapple Victoria ('Queen') is grown on Reunion Island under a large range of weather conditions where the elevation ranges from 50 to 900 m a.s.l. and annual temperatures ranges from 19 °C to 25 °C in both humid and dry areas, resulting in variable fruit size, fruit quality, selling prices of products and N leaching. Our objective was to use a crop model to improve pineapple management practices according to the diversity of conditions on Reunion Island. Farm surveys resulted in the definition of eleven criteria describing the diversity of pineapple practices to characterize pineapple farm-type: ridges, tillage, planting density, level of N fertilization and number of N application, harvest date, irrigation, farm diversification, elevation, weather and location. Three types were then identified: 1) pineapples with sugarcane the main crop located at low elevation; 2) pineapples only located at high elevation; 3) diversified farms including pineapples located at low elevation. The SIMPIÑA model was used to identify a set of best practices for each farm-type, based on fruit quality (TSS/TA), agronomic (yield), economic (income at selling), and environmental criteria (N leaching). Producing large fruits seems to be the condition to increase agronomic and economic criteria, regarless pineapple farm-type because prices of products is higher for large fruit on local market. As a result, promising management sequences selected with the model underestimated the importance of selling small fruits at local market. Overall, a decrease of level of N fertilization could reduce N leaching without reducing yield and fruit quality. This study demonstrates that multi-criteria crop simulation models used with an optimization approach provide a framework suitable for designing new management strategies of pineapple production, while taking the type of pineapple farms into account.

1. Introduction

Pineapple Victoria ('Queen') is the first fruit produced on Reunion Island, where sugarcane was once the dominant crop. With 16,000 tons produced on 360 ha, pineapple is considered as a diversification crop and represents 75% of the fruits exported from the country toward the international markets (Soler and Dorey, 2017). The marketing of fruit takes place in three markets: export, local market and transformation (corresponds to processing for pineapple juice and canned fruit) whose selling prices could be very variable because it depends on harvest season and fruit weight and quality at harvest. Pineapple grown under a wide range of conditions on the island, the elevation ranges from 50 to 900 m a.s.l., with average annual temperatures varying from 19 to 25 °C, and annual rainfall ranges from 500 mm in the west to 5000 mm in the east. Irrigation is only used on the south of the island. When cultivated away from the humid tropics or equatorial conditions, the pineapple growth rate, determined by temperature, decreasing and growing cycles get longer (Py et al., 1984). Moreover, through the use of ethylene forcing, flowering can be induced in pineapple throughout the year. This induced that harvests could occur from Januar to December. As variation in fruit size at harvest is determined in large part by plant size at forcing (Py and Lossois, 1962; Malezieux, 1988), forcing of 'Queen' pineapple is usually done at 11 or 12 months after planting at 750 m above the sea level, instead of 6 months under tropical conditions at sea level (Dubois et al., 2011). Consequently, a great variability in fruit size, fruit quality and price of selling were observed on the island.

Several studies have demonstrated the effects of seasonality on

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http://dx.doi.org/10.1016/j.agsy.2017.10.006
Received 11 October 2016; Received in revised form 4 October 2017; Accepted 9 October 2017
0308-521X/

Table 1
Distribution of harvested fruits (%) across the targeted markets (export, transformation[a], and local) according to the month of harvest and the range of fruit weight in 2014 (from Pissonier et al., 2015).

Months of harvest	Range of fruit weight (g)	Export (%)	Transformation (%)	Local (%)
December, March, April	< 600	0	0	100
	600–1000	80	10	10
	> 1000	0	90	10
October–November–January–February	< 600	0	0	100
	600–1000	50	30	20
	> 1000	0	100	0
May–June–July–August–September	< 600	10	0	90
	600–1000	100	0	0
	> 1000	10	90	0

[a] Transformation corresponds to processing for pineapple juice and canned fruit.

pineapple fruit size and quality (Py et al., 1984; Bartholomew and Paull, 1986; Bartolome et al., 1995; Dorey et al., 2016a, 2016b). However, althought the pineapple growth rate varies with elevation and season due to variations in temperature and photoperiod, it is possible to obtain larger fruits by increasing the plant size at forcing with cultural practices. Increasing the size of planting material, mainly suckers for "Queen" pineapple (Fournier et al., 2010; Dubois et al., 2011; Dorey et al., 2015), and reducing planting density (Hepton, 2003) would achieve larger plants at forcing. Water supply and N and K fertilization are also recommended to satisfy pineapple requirement and prevent growth reduction (Malezieux et al., 2003). Thus, smaller fruit can be obtained by forcing earlier. Regardless of the area of production on the island, the recommended fertilization rates are 300 kg of N ha^{-1} and 450 kg of potassium ha^{-1} in seven applications according to Fournier (2011), but recent surveys demonstrated that the actual fertilization rate varies greatly. Nevertheless, fruit quality is equally affected by season and fruit development conditions and variation in sugar and acids contents can be significant; for example, acid levels are higher during cool season and sugars are lower in mainly areas of production (Paull and Chen, 2003). The diversity of conditions for pineapple production on the island makes the prediction of yield and fruit quality very complex. However, there is a need to optimize practices in order to perform in yield and fruit quality elaboration and to ensure the best prices of product at selling.

Simulation model are useful for exploring and selecting cropping system under a wide range of conditions (Sterk et al., 2007; Semenov et al., 2009). It could be used for ex-ante assessment, as demonstrated by the use of the BANAD farm model to assess agro-ecological innovations on banana farms in Guadeloupe (Blazy et al., 2010). In agronomic sciences, biotechnical models integrated the effects of cultural practices such as irrigation and fertilization for optimizing practices like planting date or fertilization rates to perform crop management (Boote et al., 1996). But in most cases, these models concern annual crops and focus on yield. Concerning fruit, models range from simple equations that estimate fruit size and yield to a complex representation of respiration, photosynthesis, and assimilation of nutrients with the goal of predicting seasonal changes in concentrations of compounds involved in quality (Vasquez-Cruz et al., 2010). Although the latter ecophysiological models simulate how environment and plant metabolism affect fruit mass, fruit volume, and sugar content, they seldom consider how water and nitrogen (N) balances affect vegetative growth and fruit quality, except models on kiwifruit (Lescourret et al., 1999) and the recent Qualitree model on peach (Lescourret and Génard, 2005; Lescourret et al., 2011). The SIMPINA model was recently developed to simulate the growth and fruit quality of pineapple Victoria ('Queen') on Reunion Island. Model inputs include weather and practices (planting density, sucker weight at planting, level of N fertilization, irrigation). The model simulates fruit weight at harvest, N leaching, and total soluble solids (TSS):titratable acidity (TA) ratio (Dorey et al., 2015; Dorey et al., 2016a, 2016b). An economic indicator was simulated according to harvest date, fruit weight and targeted market to estimate the income at selling of products (Pissonier et al., 2015).

The objective of this study was to improve pineapple management sequences according the diversity of conditions and practices used to produce pineapple Victoria ('Queen') on Reunion Island. The SIMPIÑA model was used to optimize pineapple management sequences and evaluate them for several farm-types with multi-criteria approach defined on the base of results of surveys. After presenting the results issued from surveys to characterize pineapple farm-types with common practices, we present the results of simulations of current and promising indicators (agronomic, economic, environmental and fruit quality). The range of promising practices are then discussed for each types.

2. Materials and methods

2.1. The SIMPIÑA model

The SIMPIÑA model is a pineapple crop model developed for the Victoria 'Queen' on Reunion Island. In this model, plant growth and soil modules simulate harvest date, fruit weight, yield, and N leaching according to weather (global radiation, temperature, PET, and rainfall) and practices (planting date, irrigation, fertilization N, sucker weight at planting, planting density, and date of forcing) (Dorey et al., 2015). Quality sub-modules calculate total soluble solids (TSS) and titratable acidity (TA) of fruit at harvest (Dorey et al., 2016a, 2016b). Fruit weight and harvest date determine the targeted market (local, export, local transformation of products (Table 1) and also the selling price of products (Pissonier et al., 2015) that is used as economic indicator (Table 2). A general description of the model is presented in Fig. 1.

2.2. Characterization of practices of pineapple farmers on Reunion Island

We use the method proposed by Girard et al. (2001, 2008) and adapted by Michels et al. (2009) to characterize the diversity of practices of pineapple growers on the island based on surveys conducted in 2013 at 39 farms. One representative farm field was analysed for each

Table 2
Selling prices of pineapple fruit (€ kg^{-1}) for targeted markets in 2014 (from Pissonier et al., 2015).

Targeted market	Selling prices (€ kg^{-1})
Export	1.2
Transformation	0.8
Local	
Fruit weight < 600 g	0.5
Fruit weight: 600–900 g	0.8
Fruit weight > 900 g	1