Europ. J. Agronomy 63 (2015) 1–11

Contents lists available at ScienceDirect

European Journal of Agronomy

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

Evaluating coffee yield gaps and important biotic, abiotic, and management factors limiting coffee production in Uganda

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ARTICLE INFO

Article history:
Received 15 June 2014
Received in revised form 13 November 2014
Accepted 14 November 2014
Available online 19 November 2014

Keywords:
Production constraints
Boundary line analysis
Plant density
Mulching
Soil fertility

ABSTRACT

Coffee is Uganda's biggest export commodity, produced mainly by an estimated one million smallholder farmers (<2.5 ha). Arabica (*Coffea arabica* L.) and Robusta (*Coffea canephora* Pierre ex Froehn.) are the two coffee species grown. Robusta is dominantly cultivated at lower elevations (<1400 m) such as in Central and Northern Uganda and Arabica is dominant at higher elevations (>1400 m) such as Eastern, Southwest, and Northwest Uganda. Actual yields are far below (<30%) potential due to various biotic, abiotic, and management constraints, yet there is no quantitative information on site-specific production constraints and the yield gaps attributed to those constraints. In this study, yields and diverse production factors were monitored in 254 plots of five major coffee growing regions (i.e., Central, North, East, Southwest, and Northwest). Boundary line analysis was applied to evaluate the relative importance of the individual production factors in limiting coffee production and to quantify the associated yield gaps at regional level. The impacts of rainfall variation on coffee yield were evaluated separately by regression analysis. The results of boundary line analysis indicated that biotic constraints (coffee twig borer) and poor management practices (unproductive coffee trees and low coffee plant density) restricted Robusta production in the Central region; poor soil nutrient status (especially potassium) and lack of mulching were the causes of yield loss of Robusta grown in the Northern region. For Arabica, unfavorable soil properties (high soil pH and phosphorus concentration) and excessive number of shade trees were the most important constraints in the East; high soil magnesium concentration and poor mulching limited coffee yield in the Southwest; poor soil nutrient status (especially phosphorus and potassium) and low coffee plant density were the important yield limitations in the Northwest. Average explained yield gaps of individual coffee plot due to the most important production constraints were 45%, 52%, 57%, 49%, and 50% of attainable yield, respectively, in the Central, Northern, Eastern, Southwest, and Northwest regions. Considerably less annual precipitation was received in 2009/2010 coffee growing season compared with that in the previous three years (2006–2008). Seasonal rainfall shortage occurred in the Southwest was a significant limitation to Arabica production, while excessive rainfall across the whole growing season was associated with yield reduction in the Eastern and Northwest regions. We conclude that there was a large yield gap for both Robusta and Arabica coffee grown in Uganda. Boundary line analysis allows the evaluation of relative importance of individual production constraint directly in the plot. The important production constraints varied strongly depending on the regions, which calls for site-specific management implementations. Soil fertility can be improved by implementing integrated soil fertility management (ISFM) that makes use of nutrients from the soil, recycled crop residues, mulch and chemical fertilizers. Attentions should also be given to other management practices such as coffee plant density, unproductive coffee trees and shade trees etc.

1. Introduction

Coffee is an important cash crop in Uganda and the highland regions of East Africa such as the highlands of western Kenya, Rwanda and much of the southern and western highlands of

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http://dx.doi.org/10.1016/j.eja.2014.11.003

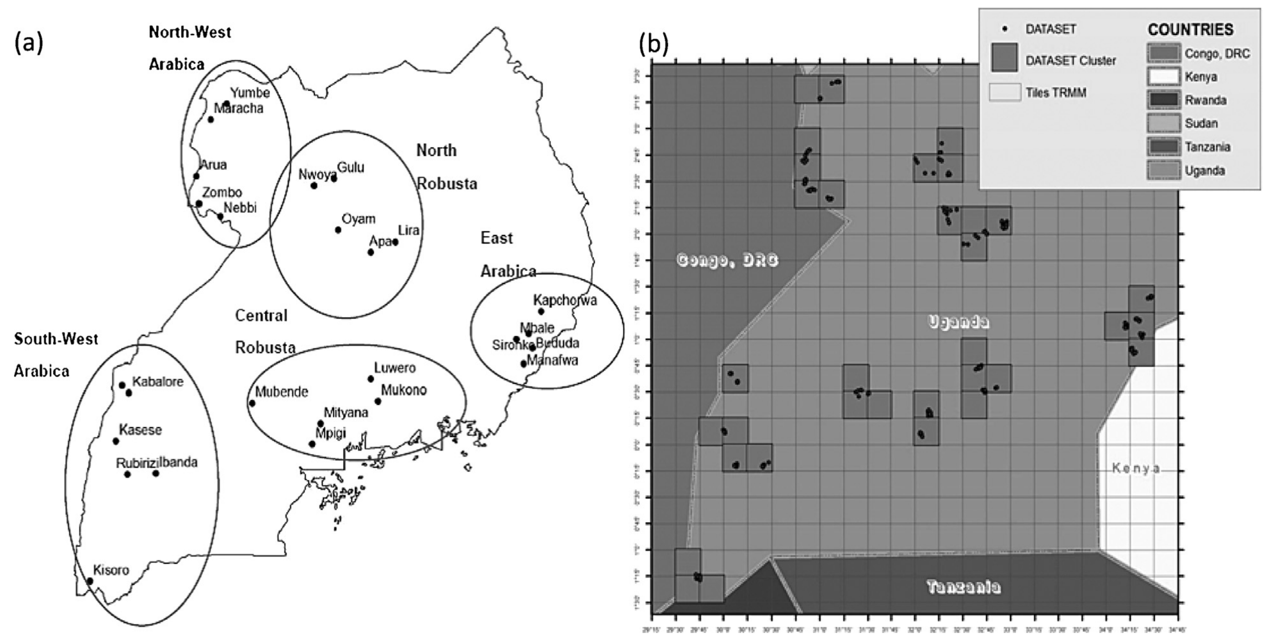

Fig. 1. The five major coffee growing regions in Uganda and districts sampled (a) Map of GPS points for rainfall data collection (b). The size of the grid cell is 625 km^2 (25 km × 25 km).

Ethiopia (Kufa et al., 2011; Nzeyimana et al., 2013; Pender et al., 2006). In Uganda, coffee accounts for approximately, 20–30% of the annual export revenue (UCDA, 2013). An estimated one million smallholder farmers owning less than 2.5 ha of land contribute 90% of Uganda's coffee production (UCDA, 2013; USDA, 2012). For smallholder farmers, coffee is the major source of cash for the households (Jassogne, 2013b). Both Arabica (*Coffea arabica* L.) and Robusta (*Coffea canephora* Pierre ex Froehn.) coffee are grown in Uganda. Robusta is widely cultivated at elevations below 1400 m, while Arabica is largely grown at elevations above 1400 m.

Uganda's coffee industry has experienced various challenges, among which low production is one of the most crucial (UCDA, 2013). There is an urgent need to increase national export revenue and to enhance coffee farmers' livelihoods. Considering the increase in population and land use pressure there is little scope to expand the land area under coffee production, leaving increasing coffee productivity as the only plausible approach.

Understanding crop yield gaps is a fundamental step in the identification of potential for yield improvement in the region (van Ittersum et al., 2013). Analysing crop yield gaps also contributes to the identification of site-specific production constraints to be addressed (Affholder et al., 2013; Fermont et al., 2009; van Ittersum et al., 2013; Wairegi et al., 2010). In this paper we define the crop yield gap as the difference between attainable yield, the maximum yield in a given region, and actual yield obtained by farmers, both obtained from on-farm surveys (Fermont et al., 2009; van Ittersum et al., 2013; Wairegi et al., 2010).

In the progress toward coffee yield improvement, efforts have focused primarily on crop protection and agronomic aspects of coffee production. The primary constraints to coffee production identified are biotic constraints (pests and diseases such as coffee twig borer (*Xylosandrus compactus*), coffee berry disease (*Colletotrichum coffeanum*), and coffee leaf rust (*Hemileia vastatrix*) etc.) (Tenywa et al., 1999; UCDA, 2013), abiotic limitations (unfertile soil, drought, and excessive rainfall) (Jassogne et al., 2013b; Shively and Hao 2012; Tenywa et al., 1999) and poor management practices (lack of mulching, pruning, and weeding etc.). Little information is available on coffee yield gaps based on direct on-farm measurements. The objectives of this study were (i) to identify the site-specific biotic and abiotic yield limiting factors and management constraints to coffee production and (ii) to understand the associated coffee yield gaps attributable to those production constraints.

2. Materials and methods

2.1. Site description

A total of 254 coffee plots in five coffee production regions (Central and Northern Robusta growing regions and the East, Southwest, and Northwest Arabica growing regions) were visited during a survey over two years from July 2010 to June 2011 (Fig. 1a). In each region, five–six districts were sampled and in each district five coffee monocrop plots and five coffee and banana intercropped plots were selected. Approximately, 40–60 coffee farmers were selected randomly and participated in the interviews in each region. Important to note here is that farmers typically own multiple coffee plots, while data was recorded for each individual coffee plot rather than the whole farm. The study sites spread over the whole country that lies between 4°12′N and 1°29′S latitude and 29°34′W and 35°00′E longitude (Mwebaze, 2002).

2.2. Data collection and processing

In each plot, global positioning system (GPS) location was used to locate plot position and estimate plot size. Waypoints were marked in each corner of the plot and used in ArcView to develop a polygonal shape file to estimate plot area (ha). Coffee yields in 2010 were obtained by farmer recall. The various terms of coffee yield described by farmers (i.e., “red cherries”, “parchment”, and “Kiboko” etc.) were converted into fair average quality (a standard form referring to green coffee beans). Annual coffee yield was obtained through dividing the cumulative annual production per plot (kg year^{-1}) by plot size (ha) and expressed as kg ha^{-1} year^{-1}. Pest and disease incidence (%) was evaluated by visually estimating the proportion of affected coffee trees among the total coffee population in the plot. The quantity and frequency of fertilization (mineral fertilizers and farm yard manure), mulching, application