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Yield gap analysis and resource footprints of Irish potato production systems in Zimbabwe

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ABSTRACT

Irish potato is the third most important carbohydrate food crop in Zimbabwe after maize and wheat. In 2012, the Government of Zimbabwe declared it a strategic national food security crop. In this study, we examine the country's potential for increasing Irish potato yield and help ease the nation's food security challenges. The magnitude of food production increase on already existing croplands depends on the difference between the current actual yields and the potential yield of the crop in the given agro-ecological environment, also called the yield gap. We used three already well-understood types of yield gap: (1) the gap between actual farmer yields, Y_a, and the maximum (potential) yield, Y_p, achieved when a crop is grown under conditions of non-limiting water and nutrient supply with biotic stress effectively controlled; (2) the gap between Y_a and the water-limited yield, Y_w, which is the maximum yield attainable under rainfed systems; and (3) the gap between Y_a, and the highest yield, Y_h, achieved by the best farmers in an agro-ecological area. A grower survey was conducted on the different potato production systems in the country in order to establish the actual yields and input application rates used in potato production. The actual potato yields were used to calculate efficiencies of natural and synthetic resources use. Potential and water-limited yields, and planting times of potato were established for the different agro-ecological regions using the LINTUL-POTATO model, a model based on interception and utilisation of incoming solar radiation. The mean actual yield observed ranged from 8 to 35% of the potential yield, translating to a yield gap of 65 to 92%, hence there is a huge potential to increase production. Simulated potential water use efficiency based on evapotranspiration range was 19–27 g potato/l against the actual water use efficiency of 2–6 g potato/l based on irrigation and rainfall. The current high fertiliser application rates and low actual yields we report, suggest inefficient fertiliser use in potato production in Zimbabwe. The average actual fungicide and insecticide use efficiencies were 0.7 and 13 kg potato/g active ingredient, respectively, across all production systems. All sampled growers lacked knowledge on integrated pest management, a concept which could possibly improve the biocide use efficiency through lowering biocide application rates while maintaining or even improving yields. Our analysis suggests that there is opportunity to improve water, nutrients and biocides resource use efficiencies and increase potato actual yields in Zimbabwe.

1. Introduction

Agriculture is currently grappling with the challenge to increase food production by 70–100% in order to meet the food needs of a rising global population expected to reach over 9 billion people by 2050 (Bruinsma, 2009; Dubois, 2011). Options to raise food production include improving output from the current croplands, expanding existing croplands or simultaneously implementing both approaches. Expanding cropping area as an option would be accompanied with the negative impacts of increased greenhouse gas (GHG) emissions and soil resources degradation (Sanchez, 2002; IPCC, 2007; Sasson, 2012). Estimates of land available for cropland expansion in Sub-Saharan Africa are contested (Young, 2000; Lambin et al., 2013; Chamberlain et al., 2014). However, converting these potentially available croplands to cultivation could entail losing the inherent biodiversity under them. Some of

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these biomes could be of high social, economic and ecological value (Licker et al., 2010). Improving yield on current croplands would imply application of high levels of inputs such as synthetic fertilisers, practices that might negatively impact soil and water quality, climate change and biodiversity (Foley et al., 2005). However, the pursuit of increasing yield on current croplands without ecologically destructive agricultural practices can be realised through the approach of *sustainable intensification* or *ecological intensification* (Garnett et al., 2013; Struik and Kuyper, 2014). This approach views intensification as a transitional process from agricultural practices generally accepted as unsustainable to those regarded as environmentally sustainable (Struik and Kuyper, 2014).

The magnitude of food production increase on already existing croplands through sustainable intensification depends on the difference between the current actual yields and the yield potential of the crop in the given agro-ecological environment. This is the basis of the yield gap concept (Van Ittersum et al., 2013). There are different ways to calculate the yield gap depending on the definitions of the yield potential and the actual yield. The yield potential, Y_p, of a particular crop cultivar is the maximum attainable yield achieved when the crop is grown under non-limiting conditions of water and nutrient supply, with biotic stress effectively controlled (Evans, 1993; Van Ittersum and Rabbinge, 1997). In irrigated systems, Y_p is determined by the amount of incident solar radiation, temperature, CO_2 concentration and plant density during the growing season (Cassman et al., 2003), assuming good health of propagules. Another important yield assessment is the water-limited yield, Y_w, which is equivalent to water-limited potential yield and is the maximum yield attainable in rainfed systems (Van Wart et al., 2013). Hence, Y_w is limited by plant available water, which is mainly determined by rainfall, soil texture, topography, soil surface cover and the plant rooting pattern. The highest actual yield (Y_h) locally attained in a given agro-ecological area is another important benchmark. Y_h has been defined by Tittonell and Giller (2013) as the water and nutrient-limited yield that can be measured in the most productive fields of resource-endowed farmers in a community. Crop simulation models are frequently used to calculate robust estimates of Y_p or Y_w, characteristic of the prevailing climatic and soil conditions in the selected agro-ecological region. Surveying good growers can provide estimates of Y_h for a particular agro-ecological region of interest. Average actual yield, Y_a, is the crop yield actually achieved by farmers in a given agro-ecological region; the crop being grown under the general management practices commonly used in the region (Cassman et al., 2003). The yield gap, Y_G, is therefore the difference between Y_p, Y_w, or Y_h and Y_a. The formula $(1 - Y_a/Y_p)$, $(1 - Y_a/Y_w)$ or $(1 - Y_a/Y_h)$ is used to provide a relative value of the Y_G. Y_G can be a useful measure to assess the efficiency of land use for crop production. Besides identifying regions where Y_G is widest (hence greatest opportunities to improve crop yield), a yield gap analysis can also be used to identify soil and management measures to close the gap (Van Ittersum et al., 2013). Additionally, yield gap analysis can be used to direct research priorities and as a benchmark to assess impact of input use, development initiatives or assess any future situation affecting land productivity (Van Ittersum et al., 2013).

The Fast Track Land Reform Program (FTLRP) in Zimbabwe at the turn of the millennium resulted in a new agrarian landscape with nearly 168,000 households resettled on approximately 11 million ha of former commercial farmland by 2009 (Ministry of Lands and Rural Resettlement (MLRR), 2009). Two resettlement models were used, the A1-resettlement model that resembles the communal area land allocation system and the A2-resettlement model that results in self-contained, small to medium scale farm units (Ministry of Lands and Rural Resettlement (MLRR), 2009). The new farmers are of diverse resource means with the majority being resource-constrained, which translates into similarly diverse farm management strategies with a bearing on yield and resource use efficiency.

Irish potato (*Solanum tuberosum* L.) is the most important horticultural crop in Zimbabwe, and the third most important carbohydrate food source after maize and wheat (The Herald, 2011). Some of the A1 and A2-resettlement model beneficiaries have started potato production adding to the already existing communal area potato farmers and the few remaining large scale commercial farmers. Growth projections target an annual potato crop of about 30,000 ha in the short to medium term (The Herald, 2011; Ackerman, 2013). Currently about 3,500 ha of the crop is planted annually (FAOSTAT, 2013). Acknowledging the increased interest in potato production and consumption, the Government of Zimbabwe declared Irish potato a national strategic food security crop on 18 May 2012 (The Herald, 2012). Before this day, only the staple maize crop had the national strategic food security crop status. The new agrarian landscape and the national strategic food security status of Irish potato present a perfect scenario to investigate the scope of increasing potato production in Zimbabwe under the current cropping systems with available land and water resources. Yield gap analysis for potato in Zimbabwe can provide a measure of unexploited food production capacity that can help address problems of food insecurity. Such an analysis will help identify regions in the country best placed to increase potato production, to evaluate the impact of resource/input use, to identify resources currently limiting Y_a and to discuss suggestions to narrow the gap.

The specific objectives of this study were: (1) to determine the potential, water-limited and actual field yields of potato in the major potato growing zones of Zimbabwe and to analyse the yield gap; (2) to establish the resource footprints (e.g., land, water, mineral fertilisers, and biocides) for potato production in the different production systems and agro-ecological zones; and (3) to offer recommendations to improve production.

2. Materials and methods

2.1. Grower survey and calculation of resource footprints

A grower survey was conducted in the traditional potato growing Highveld and Eastern Highlands regions of Zimbabwe in the period 2011 through 2014. The government agricultural extension agency, AGRITEX (Agricultural, Technical and Extension Services), selected growers to be visited for the field data collection exercise. Both irrigating and rain-fed potato farms were sampled. A minimum of 5 years continuous potato farming experience was required making the data collected dependable.

The sample included three large-scale commercial (LSC) growers and four A2-resettlement growers from the Quarantine Area located in the Nyanga Eastern Highlands agro-ecological zone. The Quarantine Area is an isolated zone created by a statutory instrument (Joyce, 1982). It is responsible for the initial potato seed multiplications and only 21 out of the 27 growers in the area are active (Ackerman, 2012). A further 18 communal area (CA), 5 A1-resttlement and one of the four remaining LSC growers, all outside the Quarantine Area completed the Nyanga Eastern Highlands sample. AGRITEX officials in Nyanga estimated about 1000 CA and less than 100 A1-resettlement growers. A total of 11 LSC and 14 A2-resettlement growers were interviewed in the extensive Highveld agro-ecological zone. According to AGRITEX officials, the Highveld has less than 30 LSC growers and about 100 A2-resettlement growers, while a few A1-resettlement and CA growers are beginning to show interest in potato growing. Data collected included gross farm and cropping land sizes, potato planting area, planting and harvesting dates, technology use levels, mineral fertiliser and biocides application rates, seed, labour, irrigation water use and the