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Factors Driving Sugar Cane Production in the Kingdom of Eswatini

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Agricultural Economics

by

Brooke D. Anderson
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This thesis is approved for recommendation to the Graduate Council.

Lawton Lanier Nalley, Ph.D.
Thesis Director

Marijke D'Haese, Ph.D.
Committee Member

Thula S. Dlamini, Ph.D.
Committee Member

Heather A. Price, Ph.D.
Committee Member

Abstract

Sugar cane is the largest industry in Eswatini with 16 percent of the total workforce working directly or indirectly in the sugar industry. Like all agricultural industries the sugar industry in Eswatini is heavily dependent on an abundant labor supply and climatic conditions. Labor efficiency and abundance is a defining factor of food security and profitability in Eswatini, having one of the highest national HIV/AIDS rates in the world. Small-scale sugar cane producers are often the hardest hit by HIV/AIDS as they traditionally rely on family labor more than hired labor. The 2016 Eswatini Vulnerability Assessment Report indicated that over half of the population in Eswatini required livelihood support, mainly in the form of food aid due to the ongoing El Niño drought. Droughts and variable weather patterns will continue to increase in frequency and magnitude globally. The implication for Eswatini is rain-fed agriculture yields could fall by up to 50 percent by 2020, threatening the livelihoods of the rural poor, a majority of whom earn their living through subsistence agriculture.

This study set out to model the effect of farm size on producer revenue in Eswatini using field-level data from 454 individual sugar cane producers from 2004-2015, coupled with location specific climatic data. Given the lack of extension services throughout Africa, one fear is that large producers may have an inherent advantage in that they can afford crop consultants, higher levels of mechanization and inputs such as inorganic fertilizer. Further, smaller farms may be hit harder by the HIV/AIDS epidemic in Eswatini. Second, given the unprecedented drought of the last decade this study estimates the effects of extreme temperatures and drought on yield and sucrose percentage, which are the drivers of revenue. This study is only one part of a larger effort to develop sustainable sugar cane production in Eswatini. Continued observation of the interaction between increasingly variable weather conditions and sugar cane production outcomes will allow refinement and enhancement of this study and agricultural policy makers in Eswatini with

important direction for sustaining production and enhancing livelihoods of the poorest of the poor in an increasingly hot future.

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Dedication

I could not have completed my graduate program without the ridiculous amounts of support and love from my family. They constantly remind me that I can accomplish anything I set my mind to do. From late night phone calls to sharing quotes with each other, my family knows exactly how to make me laugh and enjoy the craziness of life. To Ivan, for his constant positivity and insane amounts of confidence in me, and for always inspiring me to fight to create my best self. His relentless humor and encouragement to take life a little less seriously helped me stop and enjoy the little moments throughout this difficult journey to graduation. To Dana, I know she'd be proud of the adventurous, determined master-of-science I have become. I wish she could have been there to see me walk across the stage, I know she would have made a racket up in the stands with a holler and a foghorn in true Oklahoma country style. I couldn't have finished school without her teaching me how to speak my mind. I'll always remember you.

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Introduction

Sugar cane is the largest industry in Eswatini, in terms of share of Gross Domestic Product (GDP), with approximately 400 million US$ revenue per year (Eswatini Sugar Association, 2017). Approximately 16% of the total workforce is directly or indirectly employed through the sugar cane industry, which illustrates its crucial social and economic presence in the wellbeing of Eswatini (Eswatini Sugar Association, 2016). In 2016, it was estimated that the Kingdom of Eswatini (KoE) had the highest national HIV-infected prevalence rate in the world with 27.2% of adults infected (World Health Organization, 2017). Due to the high manual labor requirements of agricultural production, loss of productivity from illness associated with HIV has been estimated to be detrimental on the yields and earning abilities of infected households (Topouzis, 2003). Sugar cane producers have also faced the recent challenges of high variability in both the timing and amount of total rainfall which has lowered yield potential and increased yield variability amongst both staple and cash crops (National Disaster Management Agency, 2016). In the face of both variable weather patterns and vulnerability of smallholder farmers through losses of labor productivity, Eswatini strives for solutions through research as the kingdom's economy is based on agriculture, specifically sugar cane production.

Although the HIV rate has fallen since 2005, from 28.3% of the adult population, it is estimated there are still 220,000 individuals living with HIV in the country (World Health Organization, 2017). High HIV/AIDS levels have been linked to high losses in productivity and lowered household incomes, with a study in Nigeria showing that an average of 1,004 man-hours/year are lost due to HIV/AIDS related illness and 4,630 average man-hours/year in caring for household members that are ill (Yusuf & Purokayo, 2012). Another study within Uganda, demonstrated that due to lost labor, loss of knowledge capital, and increased dependency burdens

76% of households were producing less agricultural products within the last 10 years due to HIV (Topouzis, 2003).

Unlike the sugar cane industry in high-income countries such as the United States and Australia, which relies entirely on mechanical harvesters, sugar cane production within Eswatini requires intensive manual labor, with most producers still harvesting cane by hand ("Royal Swaziland Sugar Corporation - Operations," n.d.; United Nations Conference on Trade and Development, 2000). Multiple studies have shown that as a result of working sugarcane by hand, laborers can expect significant body mass drops from fluid loss, dehydration, and over exertion that negatively impact even healthy worker's performance (Christie, Langston, Todd, Hutchings, & Elliott, 2008; Sanders & McCormick, 1993).

The social impacts of HIV/AIDS are exemplified by shifts in the labor market, as the most impacted population are of working age (15-49) and represent a direct impact on individuals' livelihood capabilities through changes such as increased dependency burdens and loss of productivity (Food and Agriculture Organization & Office of Evaluation, 2011; Ulandssekretariatet LO/FTF Council, 2012). The risks of productivity losses and decreased earning potential disproportionately influence the rural residents who are likely to be involved in agricultural work, with 13.3% of the employed rural population working in the formal agriculture market (*Economic Census 2011: Phase 1 Report*, 2011; Falola & Jean-Jacques, 2016; Food and Agriculture Organization & Office of Evaluation, 2011). In addition, over 70% of Eswatini's population rely on subsistence farming demonstrating the breadth of impact of weather on the informal agricultural market and food security as well (Food and Agriculture Organization of the United Nations, n.d.; Masuku, Kibrige, & Singh, 2015).

Rural communities are especially inflicted by negative consequences from HIV/AIDs due to lack of access to health services, dependency on subsistence farming, and high risk of food insecurity (Masuku et al., 2015; Topouzis, 2003). Eswatini's rural community is particularly affected by productivity losses from HIV/AIDS, with a 9% decrease of rural labor force participation rate from 2007 to 2010, compared to only a 4% decrease in the urban areas (Ministry of Labour and Social Security, 2010). In addition, the 51% rural unemployment rate is double that of the urban rate at 23%, demonstrating the presence of additional challenges in rural areas (Ministry of Labour and Social Security, 2010). The impact of the HIV/AIDS epidemic manifests across all sectors of the economy through falling life expectancy, weakened social structures, decreased productivity, and the loss of immeasurable human capital (Jahan, 2016; Lule, Haacker, & World Bank, 2011; Muwanga, 2004; Watkins, 2006; Yusuf & Purokayo, 2012). Small-scale sugar cane producers, defined as under 50 hectares by the Eswatini Cane Growers Association, are often the hardest hit by HIV/AIDS as they traditionally rely on family labor more than hired labor.

Apart from infectious disease, recent climatic events within Eswatini have caused a 16% reduction in sugar output in Eswatini (Eswatini Sugar Association, 2016). In 2015/16 the El Niño drought was the worst drought Eswatini has experienced since 1992 (SEPARC, 2018). In total nominal monetary terms, the drought cost Eswatini conservatively US $306.8 million, representing a 7.01% of Eswatini's GDP in 2016 or 18.58% of government expenditure in 2016 (SEPARC, 2018). However, even with extensive experience from past droughts in 2009/10, 2007, 2001, and 1992, the country is still struggling to cope better with the effects of drought with respect to economic stability, food price stability and food security. Droughts hit Eswatini particularly hard because of its reliance on surface water (mainly rivers) to provide irrigation for cash and staple crops. Given that Eswatini is a relatively small country and droughts that effect it also have high correlations with South African droughts, and the fact that Eswatini relies so heavily on imported food from South Africa can pose food security issues.

The implication is that as droughts become more frequent regionally, their impact on the Eswatini economy could be severe, particularly on rural livelihoods who rely on substance agriculture (SEPARC, 2018). In July of 2016, the Eswatini Vulnerability Assessment Report indicated that more than half of the population (638,251 people) in the country required livelihood support, mainly in the form of food aid due to the El Niño drought. Droughts and variable weather patterns will only continue to increase in frequency and magnitude (Intergovernmental Panel on Climate Change (IPCC), 2007). The significance for Eswatini is that yields from rain-fed agriculture could fall by up to 50% by 2020. Threatening the livelihoods of the rural poor, a majority of whom earn their living through subsistence agriculture (Intergovernmental Panel on Climate Change (IPCC), 2007, 2014).

For the 2016/17 season, the rainfall from the long-term mean was down a national total of 450 millimeters (mm) (Eswatini Cane Growers Association, 2017). Specifically, the rainfall received for sugar cane producers in the Mhlume and Big Bend was 40% lower than the long term means (Eswatini Cane Growers Association, 2017). In 2016, Eswatini Sugar Association (SSA) cited compromised water availability as a negative factor in the short and medium term of the sugar cane industry due to lowered water availability and rationed irrigation for sugar cane producers (Eswatini Sugar Association, 2016). According to the SSA’s future of the Eswatini sugar industry outlook, water shortages caused by changes in traditional rainfall patterns was cited as one of the top ten risks to the sugar cane industry (Eswatini Sugar Association, 2016). Knox et al. (2010) simulated possible outcomes based on historical Eswatini weather data, predicting that the existing irrigation structures will fail to maintain the current levels of production even when assuming unconstrained water availability.

In the case of Mhlume specifically, the ability for smallholder farmers to pay for water rights is vulnerable. This leads to an inability to provide on-demand irrigation for their sugar cane crops, potentially exasperating the effects of extreme weather events within this region. Discussions led by Dr. Mkhwanazi within the Eswatini Economic Conference (2017) discussed the need for improved water management techniques, as poor governance of irrigation was identified as a potential threat to sustainability for agriculture in Eswatini.

The sugar cane industry is the foundation of the agricultural economy in Eswatini, producing over half of the total annual agricultural production output, illustrating the risks for the nation from detrimental climatic changes (Sikuka & Torry, 2017; United Nations Conference on Trade and Development, 2000). Because of the drought and extreme heat events effect on agricultural output, over 30,000 people faced food shortages between 2014-2016 and 75% of households entered the 2016-2017 planting season with depleted food stocks in Eswatini (Government of Eswatini, UN Office for the Coordination of Humanitarian Affairs, & UN Country Team in Eswatini, 2016). As climate changes increases the frequency and intensity of extreme heat events and alters traditional rainfall timing and amounts the sugar cane industry in Eswatini could face long-run sustainability issues in terms of profitability.

Sugar Cane Production in Eswatini

Sugar cane is the main livelihood of the majority of the agricultural community within Eswatini. The industry contributes to roughly 35% of the private sector employment (Eswatini Sugar Assocation, 2016). Since 2014, the El Nino weather pattern has adversely affected the entire agricultural community in Eswatini with overall food insecurity increasing from 3% in 2014 to 23.5% in 2015. The recent changes in rainfall, both in terms of timing and total amount, places up to 70% of the population depending on rain-fed agriculture at the risk of becoming food insecure (National Disaster Management Agency, 2016). Due to the fact that most sugarcane producers work small farms, at less than 50 hectares harvested, yield variability caused by changing weather patterns can greatly impact the profitability and livelihoods of these small-scale producers (Eswatini Sugar Association, 2016). Although smallholder farmers are crucial to the growth of the sugar cane industry within Eswatini, they face a disproportionate amount of challenges associated with profitability. Access to inputs have been a large constraint for the smallholders within the sugar industry, as many of these farmers do not have timely access and pay relatively higher prices than larger farms (Eswatini Cane Growers Association, 2017). The SSA requires certain disease control measures, as well as a predetermined harvest schedule and often smallholder farmers do not have access to inputs due to high costs, lack experience, or lack business skills that hinder proper compliance with the mills requirements (Masuku, 2011). The SSA provides marketing, advisory, and technical services to farmers to support adherence to these guidelines, as the guidelines are crucial to maintaining high quality output.

In 2016, sugar cane production accounted for approximately 60% of the total national agricultural output and contributed to 10% of the kingdom’s total gross domestic product (GDP) (Sikuka & Torry, 2017). One of the greatest vulnerabilities agricultural producers face is the impact of weather volatility upon crop yields due to the inability to predict or mitigate climatic risk. Sugar cane plants often have diminished yields due to suffering damage during crucial stages of development from exposure to recent adverse weather conditions. Drought is a major factor damaging sugar cane specifically due to the heightened requirement for consistent water supply in the vegetative stage of the plants life-cycle (Zingaretti, Rodrigues, da Graça, Pereira, & Lourenço, 2012). Drought is partially mitigated by the fact that in Eswatini all sugarcane is irrigated. Extreme heat events have been cited to hinder vegetative growth and sucrose accumulation, causing diminished economic returns (Hasanuzzaman, Nahar, Alam, Roychowdhury, & Fujita, 2013). Grower payment in Eswatini is based on both the volume of cane delivered to the mill, as well as the amount of sucrose contained in the cane harvest. According to studies by Glasziou and Hatch (1963), there is a negative correlation between the rate of stalk elongation and the rate of change of sugar content due to the competition for the available photosynthate, complicating profitability and climatic effect estimations on sugar cane producers (Glasziou, Bull, Hatch, & Whiteman, 1965; Hatch & Glasziou, 1963).

After planting, during the vegetative stage, extreme temperatures over 35°C can reduce total cane biomass yields, which ultimately decrease producer earnings (Ebrahim, Zingsheim, El-Shourbagy, Moore, & Komor, 1998; Moore & Botha, 2013). Sucrose formation, after the vegetative state, is even more complex as colder temperatures are desirable unless they fall below 0°C which can negatively affect the sucrose content, by inhibiting transport of sucrose from the leaves to the stalk (Ebrahim et al., 1998). While irrigation is necessary, at least in the Eswatini context, for cane production, late rains during the sucrose stage can negatively impact the percentage of sucrose (as the plant takes up water and thus dilutes the sucrose content) and thus reduces producer profits (Gowing, 1977, as cited in, Blackburn, 1984). As weather patterns become more extreme and less predictable this complex relationship between weather and profitably poses new challenges for the Eswatini sugar industry and the large percentage of the Eswatini population who rely on agriculture for their livelihoods.

Understanding the current state of global and regional climate change and its role in future crop production in Eswatini is pivotal in ensuring livelihoods and ensuring food security (Zhao & Li, 2015). Eswatini’s drought beginning in 2014 and 2015 has been linked to a decrease in food security for a number of vulnerable communities, such as small holder farmers, rural households, and those suffering from HIV/AIDS (Pound, Michicels, & Bonaficio, 2015). It is crucial for plant breeders to focus on developing improved sugar cane varieties sculpted to this new global environment. Cultivars should be tailored to be drought resistant as well as able to sustain prolonged heat above the current temperature thresholds (Zingaretti et al., 2012). The development of improved data and analysis on topics such as climate change, agricultural production, and rural development will support the government's ability to effectively assess the need for policy and better inform decision makers concerning food security and energy sector development (Bioenergy and Food Security Projects & FAO, 2013).

Problem Statement

Using on the field data provided by the SSA for 454 individual sugarcane producers from 2004-2015, coupled with location specific climatic data, this study provides a unique platform for estimating the drivers of production for sugar cane farmers in Eswatini. The goal of this study is to first, estimate if revenue per hectare is a function of farm size. Given the lack of extension services throughout Africa, one fear is that large producers may have an inherent advantage in that they can afford crop consultants, higher levels of mechanization and inputs such as inorganic fertilizer. If larger farms can more easily mechanize then it's likely the effects of HIV, in terms of lost labor and reduced labor efficiency, would affect smallholder producers more in regard to output per hectare. The government of Eswatini has made a concerted effort to reach out to small and medium size sugar cane producers, which range from 0-50 and 50-1000 hectare farms, respectively and provide extension services in an effort to increase production profitability. Currently, there has not been research regarding the relationship between farm size and sugar cane production. The findings of this study will provide the Eswatini government with important information since farm size is related to revenue per hectare. This is imperative given that sugar cane plays such a prominent role in the Eswatini economy and developing a relationship between farm size and production per hectare could drive a more granular investment into specific areas of extension research.

Second, given the unprecedented drought of the last decade this study set out to estimate the effects of extreme temperatures and drought on biomass growth (TCH) and sucrose production stages, which are the drivers of revenue. This study provides insights for sugar cane breeding efforts, public policy, and agricultural decision making related to climate change in Eswatini. Our findings provide opportunities for the international sugar cane producing community to intensify research efforts to increase resistance to heat stress during focused developmental stages. A greater understanding of extreme weather events is also needed to further Eswatini's ability to forecast the potential impacts of climate change on sugar cane yields. Further research such as this study provides attention to improving specifications of the magnitude, duration, and frequency of extreme weather events.

Literature Review

Eswatini Sugar Cane Agricultural Cycle

Factors influencing the physiological maturity of sugar cane have been studied for decades. Weather effects on sugar cane vary according to the length, extent, and during which phase of development. A background review of Eswatini agricultural cycle and abiotic stressors on sugar cane is discussed in this next section.

During the sugar cane agricultural cycle two main phases occur: biomass growth and sucrose accumulation (Ebrahim et al., 1998). In Eswatini, the autumn planting date occurs on February 1st. Biomass growth is referred to as Season 1 throughout this study and occurs from planting for 270 days. In Eswatini, season 1 is from February 1-October 28. Sucrose accumulation occurs after tiller elongation is completed and sucrose content accrual begins from day 271 until harvested. Season 2 in Eswatini lands from October 29-April 1, with estimated harvest date at April 1st.[1]

There are two main planting seasons, autumn and spring, for sugar cane in Eswatini, with the spring plant occurring on July 1 and the Autumn plant on February 1. The autumn replant occurs after summer rains and spring replant happens when the temperatures rise after the winter months, since cooler temperatures have a negative effect on cane germination and growth (N. Dlamini, personal communication, June 12, 2017). The production guide for South Africa states that the optimal time for planting is during the autumn replant if sugar cane is irrigated (Ebrahim et al., 1998). As all sugar cane throughout Eswatini is irrigated, the autumn replant (February 1) is the schedule this study's seasons are based on. Although the overarching seasonal pattern of February 1st-April 1st is followed, each individual farmer determines exactly when to plant and harvest his/her own crop according to the weather conditions as well as, fallow requirements, service provider(s) schedule, planting material availability, etc. (S. Nkambule, personal communication, June 13, 2017).

Due to the versatility of planting dates by grower, the harvest of sugar cane has a broad range, from April-December (S. Nkambule, personal communication, June 12, 2017). Harvesting is generally completed during the dry period when the stalks contain the maximum amount of sucrose. As much of the cane as possible is harvested at twelve months of age, but since the harvesting period runs for nine months, the age varies according to the environmental conditions

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[1] Planting (February and July) and Harvesting (April-December) dates based on personal communications with Sipho Nkambule, June 12, 2017.

such as precipitation and temperature. Although frost and prolonged cold temperature is the most detrimental to sugar cane yields in terms of temperature damage, this extreme is not seen in Eswatini and is therefore not a factor impacting yield in this region (N. Dlamini, personal communication, June 12, 2017). High temperatures impact both biochemical and physiological processes, and in combination with limited water, can cause depleted yield (N. Dlamini, personal communication, June 12, 2017).

Studying heat stress on plants, specifically tropical plants, has become crucial in agronomic research due to the impending threat of increasing climate temperatures. Damage from high temperature stress was observed in sugar cane through necrosis, the rolling and drying of leaves on leaf-tip and margins (Srivastava et al., 2012, as cited in, Hasanuzzaman et al., 2013). The necessity to maintain high yields of crops has encouraged many studies on heat tolerance to narrow in to the molecular level impacts of temperature. Crop plants can induce gene expression and metabolite synthesis that adapt the plant to higher temperatures, and thus creating a higher tolerance to this undesirable abiotic stressor. Plants can tolerate heat stress by creating signals that change the metabolism of the plant, but of course, this only works to a certain extent of stress. Researchers have not found a specific gene responsible for plant adaptability to heat but have determined that it is a conglomeration of biological responses. Plants accumulate different metabolites (antioxidants, osmoprotectants, heat shock proteins, etc.) and metabolic pathways, with certain processes being activated under heat stress. Investigating these interlinked responses are a crucial step to developing heat stress tolerant plants. Depending on the duration and extent of extreme temperature, plant response to heat can impact the efficiency of enzymatic reactions, RNA species, and create metabolic imbalances, and even cause cell death (Hasanuzzaman et al., 2013).

Abiotic stressors impact the plant development differently during these phases, and so the structure of this paper breaks down the impact of temperature and other variables for both seasons. First, the effect of extreme heat and cold on biomass development in season 1 is evaluated and then the influences of conditions for sucrose accumulation in season 2.

Season 1: Biomass Growth.

For the first 270 days, the sugar cane is growing through tillering and elongation. Tillering is the physiological process of repeated underground branching from compact nodal joints of the primary shoot (“Grand Growth phase,” n.d.). This provides the appropriate number of stalks required for a good yield (Ebrahim et al., 1998). If sugar cane is grown in full sunlight, there are thicker and shorter stalks, broader and greener leaves, greater rate of tiller production. If exposed to sunlight all day, there is more dry matter produced (Martin & Eckart, 1933, as cited in, Glasziou, Bull, Hatch, & Whiteman, 1965). The more time elapsed into the adult stage, the larger the impact temperature has on plant and stalk growth (Glasziou et al., 1965).

During the biomass growth stage, cold weather has the most significant negative impact on the ability for sugar cane to grow, as there is no growth (biomass production) below 12 or 15 degrees (Verret & Das, 1927; Sartorius, 1929; Ryker & Edgerton, 1931, as cited in, Ebrahim et al., 1998). In addition to growth, extremely cold temperatures (15℃) also had an impact on the shoot and root system with an 85% decrease of ratio from moderate temperature (27 ℃) according to a study by Ebrahim (1998). Within the same study, plants grown at 27℃ had the highest number of internodes, in comparison to those grown at 15℃ and 45℃ degrees, throughout the growth period. Total biomass production was 1/2-1/3 less at 45℃, in comparison to plants grown at 15℃ and 27℃, showing that extreme temperatures are not optimal for biomass growth (Ebrahim et al., 1998).

Another study by Moore found that although leaf and tiller emergence increase up to 38°C compared to those at 33°C, photosynthetic rate reduces past this point, indicating that extended periods of time with warm temperatures could be detrimental (Moore & Botha, 2013; Blackburn, 1984). Warmer temperatures are required for the growth stage but increasing temperature above the threshold of 35°C hinders growth and is seen by a physically wilted cane with a lack of growth occurring regardless of water supply (Moore & Botha, 2013). Extremely warm temperatures can also impact sucrose content with any temperature higher than 35°C resulting in a limitation of photosynthesis and thus hindering sucrose accumulation (Hasanuzzaman et al., 2013). The reduced growth rate under high temperatures have been attributed to a decrease in net assimilation rate (NAR) within sugar cane (Srivastava et al., 2012, as cited in, Hasanuzzaman et al., 2013).

A study by Das determined that the optimum temperature for dry matter for sucrose production and concentration in the stalk is 30°C. Sugar yields also correlate well with day degrees that are summed above 18 or 21 degrees (Das, 1933, as cited in, Glasziou et al., 1965). Clements later confirmed that during the juvenile stage, the optimum temperature for plant and stalk growth is 30°C, with sugarcane producing the highest sugar yields at growth temperatures between 25-35°C (1980, as cited in Ebrahim et al., 1998).

Season 2: Sucrose Accumulation.

For high yielding sugar cane sucrose accumulation, also referred to as ripening, must occur. In short, sucrose accumulation ensues when sucrose is transported through the phloem from the leaves towards the shoot and is accumulated in storage organs (Hatch & Glasziou, 1963).

Exporting sucrose from the leaves to the stalk of the sugar cane is subdued during low temperatures, indicating that translocation is very sensitive to cooler temperatures (Ebrahim et al., 1998). Gowing conducted a study in Iran and confirmed that the process of sucrose accumulation is sensitive to high levels of rainfall and requires that temperature does not dip below 10 degrees. A decrease in temperature below 10 degrees can cause irreparable cell damage in the sugar cane (1977, as cited in, Blackburn, 1984).

Deressa explores how warmer temperatures during sucrose accumulation are not optimal for sugar cane. If temperature is raised to 45℃, there is an elevated leaf respiration which causes a reduction in the amount of available sugar for translocation. The increased respiration causes lower sucrose concentration in the internodes of plants grown at 45℃ than at 15℃ or 27℃, showing that high temperatures have a negative impact on sucrose content**.** In other studies, it has been postulated that translocation from leaves to other parts of the plant is faster at lower temperatures, confirming the theory that higher temperatures decrease yield in sugar cane. The failure of the plants to store sugars at a high temperature is because the available photosynthate for growth is being utilized. The photosynthate causing growth in the sugar cane is not supportive for sucrose accumulation (Deressa, Hassan, & Poonyth, 2005).

Climate Change Impacts on Sugar Cane Production in Southern Africa

The impact of changing weather patterns has been studied several times in relation to sugarcane production (Inman-Bamber & Smith, 2005; Knox, Rodríguez Díaz, Nixon, & Mkhwanazi, 2010; Reinhard, Knox Lovell, & Thijssen, 2000; Zhao & Li, 2015). Zhao examines the effects of climate change in the top ten sugar cane producing countries, finding that the greatest yield variations occurring in developing countries across years (1973-2013) in locations of unpredictable rainfall and temperatures (Zhao & Li, 2015). Low profits for sugar cane producers in these regions are vulnerable due to low cane price, high costs of production due to inputs (Zhao & Li, 2015). The study concluded that physiologically the most problematic situation for sugar cane production is intense extreme climatic events occurring more frequently, requiring new sugar cane cultivars bred for heat and drought resistance (Zhao & Li, 2015).

In one study by Knox, the CANEGRO model simulated several possible outcomes of climate change on sugarcane production in Eswatini. A focus of the study was to assess the impact on resource availability and water demand, which accounts for both irrigation abstraction and crop production. It was found that there would be a 20-22% increased need for irrigation from the baseline to continue with the current optimal levels of production (Knox et al., 2010). Currently, all Eswatini sugarcane is irrigated as it is crucial to the production process (Inman-Bamber & Smith, 2005). A majority of the water for Eswatini agriculture (96%) is currently used for sugarcane production (Matondo, Graciana, & Msibi, 2004, as cited in, Knox et al., 2010).

Both modelling and production factors help to evaluate the efficiencies involved within a profitable and productive sugarcane industry (Keating, Robertson, Muchow, & Huth, 1999; Reza, Riaza, & Khan, 2016; Thabethe, 2013). Within Keating's research, the use of the modelling system, APSIM framework, within the sugarcane industry was evaluated. The goal of the article was to simulate sugarcane crop to use a whole systems approach to production. The authors hoped to increase the ability of researchers to evaluate productivity of sugarcane. In conclusion, the article confirmed that this modelling system is adequate for observing most physiological performance indicators of crops over a variety of production scenarios (Keating et al., 1999).

Eswatini Sugar Cane Industry

The SSA manages all exported raw sugar produced in Eswatini. World sugar cane production has tripled in the last 41 years due to increasing demand for this product (Zhao & Li, 2015). The two main markets for Eswatini 's export sugar include the South African Customs

Union (SACU) and the European Union (EU). SACU accounts for 45-70% of the sugar sales, and the EU around 24-55%, although sales to the EU have fallen in recent years due to low prices (Sikuka & Torry, 2017).

A general review of Sub Saharan Africa's sugar cane production discovered diverse methods of production, scale, and industry models. The study found that to best discuss the environmental, social, and technical impacts of the industry, the evaluation must be context specific. Ultimately, the review did not conclude with a good/bad or sustainable/unsustainable consensus of the sugar cane industry within the Sub-Saharan region. Instead, suggesting a multi-disciplinary analysis and planning for context-specific industries as crucial for encouraging responsible sector sustainability. This synergistic approach, including various scales and disciplines, is particularly crucial for water management and livelihoods for farmers within the industry (Hess et al., 2016).

Another challenge for the industry, is presented as the need for research within the specific contexts to evaluate the industry model's ability to create equitable economic growth for all those involved. The impacts of sugar cane are widespread across social and environmental spheres with a high level of infrastructure required for irrigation, mills, and other factors (Hess et al., 2016). Looking at smallholder sugar cane growers specifically, brings to the forefront the potential challenges for this crucial segment of Eswatini's sugar cane industry.

Smallholder Sugar Cane Grower Challenges

A South African case study evaluated various types of efficiencies within the sugarcane sector by gathering information on farmer characteristics such as farmer education, access to extension/credit, and market access for improved technologies. The results showed that small-scale farmers were lacking efficiencies in all types tested; technical, allocative, and cost. It was found that there was a need for better relationships between agricultural producers and sugar cane mills. The author suggests technical guidelines for small farmers as an incentive for punctual delivery of high quality sugar cane (Thabethe, 2013).

A study in Bangladesh found that outdated production practices, lack of adequate labor, and low-quality sugar harvests are factors that contribute greatly to low productivity and profitability in sugar mills (Reza et al., 2016). In addition, farmers were not reaching their optimum production levels due to many reasons including, credit shortages, early or late harvests, environmental resistance, and late planting. The results concluded that lack of proper training, inadequate supply of inputs, and extended harvest periods were the major constraints for producer profitability (Reza et al., 2016).

Masuku used personal interviews with smallholder farmers and representatives of farmer cooperatives/associations' to analyze the determinants of performance of the cane growers in the sugar industry in Eswatini (Masuku, 2011). Using multiple linear regression, Masuku analyzed the impact of several factors on the profitability of the farmer. The results determined the profitability of the farmers was positively affected by several factors including; the yield per hectare, sucrose content, and changes in production quotas'. Farmer experience negatively impacted the profitability of sugar cane farmers. The author explains that this could be due to confidence in ability and thus negligence in risk taking activities such as crop husbandry. Distance to the mill was also found to be negatively influencing production performance. Masuku concludes with suggestions that improving production efficiency and reduced input costs could increase grower profits (Masuku, 2011).

An examination of smallholder sugar cane growers in Eswatini was conducted to understand the relationship between social and economic aspects, as well as the influence of agricultural development policies surrounding the industry (Terry & Ogg, 2016). The authors highlight the crucial role of the sugar industry for Eswatini's economy and focused especially on the increasing importance of smallholder farmers within the profitability of this industry. The review studies the evolution of the industry from focuses on benefits for the elite, to widespread livelihood improvements for rural, small-scale farmers.

The shortage of skilled small-scale sugar cane producers is a concern that should be addressed during the expansion and improvement of the sugar cane industry within Eswatini. Three main areas of focus have been presented as potential solutions to lack of grower skills; agronomic assistance through SSA extension, management abilities and industry knowledge, and financial management skills (United Nations Conference on Trade and Development, 2000). Currently, among the many long-term strategic objectives of the SSA is the objective of crop protection and extension strategy. This strategy hopes to identify and prevent pests and diseases and works to provide extension services to producers to develop skills to ensure the highest possible yields (Eswatini Sugar Association, 2016).

Methodology

Data

Production data from 454 Eswatini farmers was received from the SSA in correspondence with the Eswatini Economic Policy Analysis and Research Centre (SEPARC) for harvest years 2004-2015. At harvest, every sugar cane producer in Eswatini sells their yield to one of the three processing mills: Simunye, Ubombo, and Mhlume. Each producer has been assigned a unique identifier code (farmer ID), to ensure the privacy of the producers during the data analysis. The mills use tons of cane per hectare harvested (TCH) and sucrose percentage to calculate the payment for the purchase of each producer's sugar cane. In addition to TCH and sucrose, other variables such as farmer ID, area harvested, district, cane age at harvest, and farm size by hectares for each year were included to help with analyses of production variability.

Originally, the dataset received from the SSA included data up to harvest year 2015-2016. Due to a severe drought, the yield from this year had wide variability and thus would have skewed the results and so this harvest year was eliminated from the dataset. To ensure that adequate information for each farmer was available to draw results from, only farmers with more than 5 observations were included in the analysis. This allows for at least 5 years of yield statistics to each farmer ID. Due to the unlikely chance of uprooted crop or large acquisitions, any farmers that increased or decreased the number of hectares harvested by larger than 50% its size from the year before was not included in the dataset. Historical sucrose price (SZL E/ton of sucrose) data was sourced from the SSA together with the grower revenue calculation equations.

Daily weather data was gathered for maximum, minimum, average temperatures, and precipitation from aWhere. aWhere is a global agriculture focused model environment that focuses on collecting data points to increase insight into agricultural and climatic trends (“aWhere,” 2017). The weather dataset used within this study consisted of daily weather from 2008-2016 for districts Mhlume, Simunye, and Big Bend. Note that Big Bend is near the area of the Ubombo milling site, and thus was used for Ubombo’s weather data. Precipitation was measured by millimeters (mm) and all temperatures are reported in Celsius (℃).

Data Analysis

Initial data analysis included descriptive statistics based around the means and standard deviations of variables based on yearly, district, and kingdom wide divisions. Multiple linear regression models were used to estimate the effect of farm size, cane age, and climatic variables on production through tons of cane harvested per hectare and sucrose percentage. By analyzing the driving factors on sugar cane production, farm size and climatic variables can be pinpointed for policy implications, as well as discovering areas in need of future research. Data was analyzed in R Studio version 1.0.143, with regressions being run with the linear model (lm) function inside of the package stats. Figures were created through R Studio function ggplot2 and Microsoft Excel (Wickham, 2009).

Several regression models were analyzed through the systematic evaluation of each variable's robustness within the production estimates. Normality of means was assumed through the Central Limit Theorem (n>30).. The dummy variables that are used as the reference within the model intercepts are as follows: the Year 2004-2005, the District of Mhlume, and the Hectare Class: Large. Initially, the production (and weather) data was divided by district (Mhlume, Simunye, and Ubombo) to understand the production effects within each region of the kingdom. A regression was calculated for all three districts and the pooled dataset for all of Eswatini within each model, allowing for four regressions per model. The final models, Regression 6a and 6b, were the result of the best fitting estimators to provide the most accurate representation of production drivers within Eswatini.

Model 1.

Regression 1a and 1b includes *Year, Med, Small, Age, AgeSq* which represents; year (2004-2015), hectare class medium dummy variable, hectare class small dummy variable, age, age squared, respectively. Regression 1a is regressed upon tons of cane per hectare (*TCH*) while Regression 1b is regressed upon sucrose percentage as denoted by SUC.

$$\begin{aligned} TCH = \beta_T + \beta_{T,year1} Year1 + \beta_{T,year2} Year2 \; + \beta_{T,year\ldots n} Year \ldots n \; + \\ \beta_{T,Med} Med + \;\; \beta_{T,Sm} Small + \beta_{T,Age} Age + \beta_{T,AgeSq} AgeSq + \varepsilon_T \end{aligned} \tag{1a}$$

$$\begin{aligned} SUC = \beta_S + \beta_{S,year1} Year1 + \beta_{S,year2} Year2 \; + \beta_{S,year\ldots n} Year \ldots n \; + \\ \beta_{S,Med} Med + \;\; \beta_{S,Sm} Small + \beta_{S,Age} Age + \beta_{S,AgeSq} AgeSq + \varepsilon_S \end{aligned} \tag{1b}$$

Equation 1a.

TCH = Tons of Cane per Hectare
β_T = Coefficient for the intercept
$\beta_{T,year1\ldots n}$ = Coefficient for the 10 dummy year variables, 2005-2015
$\beta_{T,x}$ = Coefficient estimate representing expected change in *TCH* with a unit change in *x* variable
ε_T = random error term

Equation 1b.

SUC = Sucrose Percentage
β_S = Coefficient for the intercept
$\beta_{S,year1\ldots n}$ = Coefficient for the 10 dummy year variables, 2005-2015
$\beta_{S,x}$ = Coefficient estimate representing expected change in *SUC* with a unit change in *x* variable
ε_S = random error term

Model 2.

Within Regression 2a and 2b hectare class dummy variable (Med, $Small$) is replaced by the continuous variable, hectares harvested, denoted by $Hectare$. All other variables, *Year, Age,* and *AgeSq*, remain the same as Regression 1. Regression 2a is regressed upon tons of cane per hectare (TCH), while Regression 2b is regressed upon sucrose percentage as denoted by SUC.

$$TCH = \beta_T + \beta_{T,year1}Year1 + \beta_{T,year2}Year2 + \beta_{T,year\ldots n}Year \ldots n + \beta_{T,Ha}Hectares + \beta_{T,Age}Age + \beta_{T,AgeSq}AgeSq + \varepsilon_T \quad (2a)$$

$$SUC = \beta_S + \beta_{S,year1}Year1 + \beta_{S,year2}Year2 + \beta_{S,year\ldots n}Year \ldots n + \beta_{T,Ha}Hectare + \beta_{S,Age}Age + \beta_{S,AgeSq}AgeSq + \varepsilon_S \quad (2b)$$

Equation 2a.

TCH = Tons of Cane per Hectare
β_T = Coefficient for the intercept
$\beta_{T,year1\ldots n}$ = Coefficient for the 10 dummy year variables, 2005-2015
$\beta_{T,x}$ = Coefficient estimate representing expected change in *TCH* with a unit change in *x* variable
ε_T = random error term

Equation 2b.

SUC = Sucrose Percentage
β_S = Coefficient for the intercept
$\beta_{S,year1\ldots n}$ = Coefficient for the 10 dummy year variables, 2005-2015
$\beta_{S,x}$ = Coefficient estimate representing expected change in SUC with a unit change in *x* variable
ε_S = random error term

Model 3.

Regression 3a and 3b includes an additional variable, hectare harvested squared ($HectareSq$), to measure the non-linear aspects of farm size. All other right-side factors are the same as before in Regression 2. Regression 3a is regressed upon tons of cane per hectare (TCH), while Regression 3b is regressed upon sucrose percentage as denoted by SUC.

$$TCH = \beta_T + \beta_{T,year1}Year1 + \beta_{T,year2}Year2 + \beta_{T,year\ldots n}Year \ldots n + \beta_{T,Ha}Hectares + \beta_{T,HaSq}HectareSq + \beta_{T,Age}Age + \beta_{T,AgeSq}AgeSq + \varepsilon_T \tag{3a}$$

$$SUC = \beta_S + \beta_{S,year1}Year1 + \beta_{S,year2}Year2 + \beta_{S,year\ldots n}Year \ldots n + \beta_{T,Ha}Hectares + \beta_{T,HaSq}HectareSq + \beta_{S,Age}Age + \beta_{S,AgeSq}AgeSq + \varepsilon_S \tag{3b}$$

Equation 3a.

TCH = Tons of Cane per Hectare
β_T = Coefficient for the intercept
$\beta_{T,year1\ldots n}$ = Coefficient for the 10 dummy year variables, 2005-2015
$\beta_{T,x}$ = Coefficient estimate representing expected change in TCH with a unit change in *x* variable
ε_T = random error term

Equation 3b.

SUC = Sucrose Percentage
β_S = Coefficient for the intercept
$\beta_{S,year1\ldots n}$ = Coefficient for the 10 dummy year variables, 2005-2015
$\beta_{S,x}$ = Coefficient estimate representing expected change in SUC with a unit change in *x* variable
ε_S = random error term

Model 4.

Regression 4 eliminates the hectares harvested variables ($Hectare$, $HectareSq$) and replaces it with the dummy variables for individual farmer identifier codes, as represented by $FarmerID_1 - FarmerID_k$. There are 454 unique farmer ID's, with IDM001 being the reference farmer ID, and each are represented by $FarmerID_k$. The year and cane age variables remain as, *Year*, *Age*, and *AgeSq*. Regression 4a is regressed upon tons of cane per hectare (TCH), while Regression 4b is regressed upon sucrose percentage as denoted by SUC.

$$\begin{aligned} TCH = {} & \beta_T + \beta_{T,year1}Year1 + \beta_{T,year2}Year2 + \beta_{T,year\ldots n}Year\ldots n + \\ & \beta_{S,ID1}FarmerID1 + \beta_{T,ID2}FarmerID2 + \beta_{T,ID\ldots k}FarmerID..k + \\ & \beta_{T,Age}Age + \beta_{T,AgeSq}AgeSq + \varepsilon_T \end{aligned} \tag{4a}$$

$$\begin{aligned} SUC = {} & \beta_S + \beta_{S,year1}Year1 + \beta_{S,year2}Year2 + \beta_{S,year\ldots n}Year\ldots n + \\ & \beta_{S,ID1}FarmerID1 + \beta_{T,ID2}FarmerID2 + \beta_{T,ID\ldots k}FarmerID..k + \\ & \beta_{S,Age}Age + \beta_{S,AgeSq}AgeSq + \varepsilon_S \end{aligned} \tag{4b}$$

Equation 4a.

TCH = Tons of Cane per Hectare

β_T = Coefficient for the intercept

$\beta_{T,year1\ldots n}$ = Coefficient for the 10 dummy year variables, 2005-2015

$\beta_{T,ID1}FarmerID1..k$ = 453 dummy variables for Farmer ID 1-454

$\beta_{T,x}$ = Coefficient estimate representing expected change in *TCH* with a unit change in *x* variable

ε_T = random error term

Equation 4b.

SUC = Sucrose Percentage

β_S = Coefficient for the intercept

$\beta_{S,year1\ldots n}$ = Coefficient for the 10 dummy year variables, 2005-2015

$\beta_{S,ID1}FarmerID1\ldots k$ = 453 dummy variables for Farmer ID 1-454

$\beta_{S,x}$ = Coefficient estimate representing expected change in *SUC* with a unit change in *x* variable

ε_S = random error term

Model 5.

Regression 5 presents a new factor, the previous years' TCH for regression 5a and previous years' sucrose percentage for regression 5b, to replace the lengthy dummy variable of farmer ID. The year and cane age variables continue consistently as, year, cane age, and age squared. Regression 5a is regressed upon tons of cane per hectare (TCH), while Regression 5b is regressed upon sucrose percentage as denoted by SUC.

$$TCH = \beta_T + \beta_{T,year1} Year1 + \beta_{T,year2} Year2 + \beta_{T,year \ldots n} Year \ldots n + \beta_{T,Prev} Previous + \beta_{T,Age} Age + \beta_{T,AgeSq} AgeSq + \varepsilon_T \tag{5a}$$

$$SUC = \beta_S + \beta_{S,year1} Year1 + \beta_{S,year2} Year2 + \beta_{S,year \ldots n} Year \ldots n + \beta_{S,Prev} Previous + \beta_{S,Age} Age + \beta_{S,AgeSq} AgeSq + \varepsilon_S \tag{5b}$$

Equation 5a.

TCH = Tons of Cane per Hectare
β_T = Coefficient for the intercept
$\beta_{T,year1 \ldots n}$ = Coefficient for the 10 dummy year variables, 2005-2015
$\beta_{T,x}$ = Coefficient estimate representing expected change in *TCH* with a unit change in *x* variable
ε_T = random error term

Equation 5b.

SUC = Sucrose Percentage
β_S = Coefficient for the intercept
$\beta_{S,year1 \ldots n}$ = Coefficient for the 10 dummy year variables, 2005-2015
$\beta_{S,x}$ = Coefficient estimate representing expected change in *SUC* with a unit change in *x* variable
ε_S = random error term

Model 6.

Regression 6 is the final, best fitting model for estimating the production drivers for TCH and sucrose percentage. Robust impacts based on continued statistical significance throughout the previous models rendered the inclusion of Age, $AgeSq$ and $Hectare$ within the final models.

In addition, each model improves the explanatory power and ability for policy implications, with Model 6 best explaining the influences of farm size and climatic variables on production. The best measurement of individual farmer's management and production practices was previous years' TCH and sucrose percentage, as represented by $Previous$. Previously, $Year$ was used in Models 1-5 as a proxy for weather effects on production. $Year$ was replaced by specific critical thresholds and weather variables within Model 6 to better represent how the environment influences the Eswatini grower's yields and sucrose content. Model 6a, as regressed on TCH, focuses on the critical threshold, Time above 35°C, as this critical threshold hinders biomass growth resulting in lower cane weight. Regression 6b estimates the sucrose percentage of the cane since sucrose accumulation occurs in the second season and is impacted by cold temperatures and excessive precipitation. To better estimate the sucrose impacts, the elements average minimum temperature and precipitation are included. Model 6 includes the best fitting estimators, tested throughout Model 1-5, for cane age, farm size, and environmental factors on TCH and sucrose percentage.

$$TCH = \beta_0 + \beta_{S,Age}Age + \beta_{S,AgeSq}AgeSq + \beta_{S,Hectares}Hectares + \beta_{S,Previous}Previous + \beta_{S,Tabove35}Tabove35C + \varepsilon_S \tag{6a}$$

$$SUC = \beta_0 + \beta_{T,Age}Age + \beta_{T,AgeSq}AgeSq + \beta_{T,Hectares}Hectares + \beta_{T,Previous}Previous + \beta_{T,AvgMin}AvgMin + \beta_{T,Precip}Precip + \varepsilon_S \tag{6b}$$

Equation 6a.

TCH = Tons of Cane per Hectare
β_T = Coefficient for the intercept
$Tabove35C$ = Time (Degree Days) above 35°C
$\beta_{T,x}$ = Coefficient estimate representing expected change in *TCH* with a unit change in *x* variable
ε_T = random error term

Equation 6b.

SUC = Sucrose Percentage

β_S = Coefficient for the intercept
$AvgMin$ = Average daily minimum temperature in season 2
$Precip$ = Average daily precipitation in season 2
$\beta_{S,x}$ = Coefficient estimate representing expected change in SUC with a unit change in x variable
ε_S = random error term

Marginal Effects.

The marginal effect equation was used to find the amount of change in production from a one-unit change in hectares harvested squared and cane age squared. Note that since the one-unit change was more applicable in this study, and not the instantaneous rate of change, the following Equation 1 was used rather than the customary partial derivative. The analysis of variables, hectares harvested squared and age squared ($HectareSq, AgeSq$) was based upon the marginal effect of the variable on TCH and sucrose percentage. Equation 1 demonstrates how one more month of age influences yield (1a) and sucrose percentage (1b), while all other variables are held constant. Equation 2 demonstrates how one hectare harvested effects TCH (2a) and sucrose percentage (2b), while all other variables are held constant.

Equation 1. Marginal Effect of Age.

Equation 1 calculates the marginal effect, being the effect of a one unit change in cane age and age squared on TCH (1a) and Sucrose percentage (1b). The equation allows for measuring the impact of any cane age on production by simply changing the age within the variable *A*. Note that Figure 18 and 19 uses coefficient estimates for cane age by month, β_4, and cane age squared, β_5, derived from Model 6 for the marginal effect calculation as discussed within the results section.

$$\text{Marginal effect of Age on expected } TCH = \beta_4 + 2\beta_5 A + \beta_5 \tag{1a}$$

$$\text{Marginal effect of Age on expected } SUC = \beta_4 + 2\beta_5 A + \beta_5 \tag{1b}$$

β_4 = Coefficient estimate representing the expected change in age variable with a unit change in *TCH, SUC*.
β_5 = Coefficient estimate representing the expected change in age squared variable with a unit change in *TCH, SUC*.
A = number of months of cane age

Equation 2. Marginal Effect of Hectares.

Equation 2 calculates the marginal effect of hectares harvested and hectares harvested squared on TCH (2a) and sucrose percentage (2b). The equation can be calculated for farms of all sizes to measure the impact of hectares harvested on production by modifying the number of hectares within the variable *H*. Note that Figure 16 and 17 use coefficient estimates for hectares harvested, β_6, and hectares harvested squared, β_7, derived from Model 3 for the marginal effect calculations as discussed within the results section.

$$\text{Marginal effect of Hectares on expected } TCH = \beta_6 + 2\beta_7 H + \beta_7 \tag{2a}$$

$$\text{Marginal effect of Hectares on expected } SUC = \beta_6 + 2\beta_7 H + \beta_7 \tag{2b}$$

β_6 = Coefficient estimate representing the expected change in Hectare harvested variable with a unit change in *TCH, SUC*.
β_7 = Coefficient estimate representing the expected change in Hectare harvested Squared variable with a unit change in *TCH, SUC.*
H = number of hectares harvested

Producer Revenue. Equation 3.

Eswatini producers are paid according to the number of tons of cane per hectare and level of sucrose percentage of the cane, which is calculated as sucrose produced. Farm revenue is then calculated by including the price of sucrose in that year, denoted as ρ within the producer revenue equation (3). The average sucrose price (SZL/ ton) from 2008-2015 was used to calculate producer revenues (T. Dlamini, personal correspondence, April 9, 2018).

$$\mathcal{R} = \rho(\, TCH * SUC) \tag{3}$$

$\mathcal{R}$ = Producer revenue per ton
ρ = Sucrose Price; Swazi emalangeni/ton of sucrose
$(TCH * SUC)$ = Sucrose produced (tons per hectare)
TCH = Tons of Cane per Hectare
SUC = Sucrose Percentage

Marginal Effects of Temperature on TCH.

To calculate how incremental temperature and precipitation changes would impact revenue, first the impacts of changing climate on TCH and sucrose percentage production were calculated. To demonstrate the effect of extreme temperature exposure on TCH, the estimated TCH (as originally calculated by Model 6a) was re-calculated with all other values staying the same and using the mean degree days above 35℃ from the hypothetical weather dataset for +1℃, -1℃, +0.5℃ and -0.5℃. The absolute change in TCH (for each temperature change) was calculated by taking the difference between the original estimated TCH from Model 6a and the re-calculated hypothetical weather dataset. The hypothetical dataset was created by increasing and decreasing temperatures by 1℃ and 0.5℃, as well as increasing and decreasing precipitation by 2.5%, 5%, and 10%.

$$TCH_1 = \beta_0 + \beta_{S,Age}Age + \beta_{S,AgeSq}AgeSq + \beta_{S,Hectares}Hectares + \beta_{S,Previous}Previous + \beta_{S,Tabove35}Tabove35C + \varepsilon_S \tag{6a}$$

$$TCH_2 = \beta_0 + \beta_{S,Age}Age + \beta_{S,AgeSq}AgeSq + \beta_{S,Hectares}Hectares + \beta_{S,Previous}Previous + \beta_{S,Tabove35}HYPOTabove35C + \varepsilon_S$$

$HYPOTabove35C$ = The mean degree days (time) above 35℃ as calculated on the hypothetical weather dataset for +1℃, -1℃, +0.5℃ and -0.5℃
$Tabove35C$ = The mean degree days (time) above 35℃ as calculated on the actual weather dataset

TCH_1 - TCH_2 = Absolute Change in TCH (for each scenario)

Marginal Effects of Temperature and Precipitation on Sucrose Percentage.

To demonstrate the effect of changes in the average minimum temperatures on sucrose percentage, the estimated percentage (as originally calculated by Model 6b), was re-calculated with all other values staying the same, but using the mean average minimum temperature from the hypothetical weather dataset for +1℃, -1℃, +0.5℃ and -0.5℃. To demonstrate the effect of changes in precipitation on sucrose percentage, the estimated percentage (as originally calculated by Model 6b), was re-calculated with all over values staying the same, but using the mean average precipitation from the hypothetical weather dataset for -10%, -5%, -2.5%, 2.5%, 5%, and 10% changes in precipitation, with the mean minimum temperature constant at the values for the hypothetical dataset for +1℃, -1℃, +0.5℃ and -0.5℃.

The absolute change in sucrose percentage (for each temperature and precipitation change) was calculated by taking the difference between the original estimated sucrose percentage from Model 6b and the re-calculated sucrose percentage based on the hypothetical weather dataset values for minimum average temperature and precipitation.

$$SUC_1 = \beta_0 + \beta_{T,Age}Age + \beta_{T,AgeSq}AgeSq + \beta_{T,Hectares}Hectares + \beta_{T,Previous}Previous + \beta_{T,AvgMin}AvgMin + \beta_{T,Precip}Precip + \varepsilon_S \tag{6b}$$

$$SUC_2 = \beta_0 + \beta_{T,Age}Age + \beta_{T,AgeSq}AgeSq + \beta_{T,Hectares}Hectares + \beta_{T,Previous}Previous + \beta_{T,AvgMin}HYPOAvgMin + \beta_{T,Precip}HYPOPrecip + \varepsilon_S$$

$HYPOAvgMin$ = The mean average minimum temperature in season 1 as calculated on the hypothetical weather dataset for +1℃, -1℃, +0.5℃ and -0.5℃

$HYPOPrecip$ = The mean precipitation in season 1 as calculated on the hypothetical weather dataset for -10%, -5%, -2.5%, 2.5%, 5%, and 10% changes in precipitation

$Avg\ Min$ = The mean average minimum temperature in season 1 as calculated on the actual weather dataset

$Precip$ = The mean precipitation in season 1 as calculated on the actual weather dataset

SUC_1 - SUC_2 = Absolute Change in Sucrose percentage (for each scenario)

Climatic Revenue Change.

The absolute change in TCH and sucrose percentage were then used within equation 3 as TCH and SUC and to calculate the change in revenue due to the hypothetical weather scenarios.

$$\mathcal{R}_C = \rho(Absolute\ Change\ in\ TCH * Absolute\ Change\ in\ SUC)$$

$\mathcal{R}_C$ = Absolute Change in Revenue

Results

Descriptive Statistics

A total of 4,178 observations were analyzed across 11 harvest years consisting of 454 individual farmers in three growing districts (Table 1, Appendix 1). The eleven-year average harvest per grower was an average of 14.18% sucrose, average yield of 83.64 tons of cane per hectare (TCH), and 10,716 total tons of cane (Table 1). The harvested TCH and sucrose percentage had a standard deviation of 29.94 tons per hectare and 1.08%, respectively (Table 1).

The average age of the sugar cane harvested was 12.17 months, with a standard deviation from this mean at 2 months. The relative large standard deviation, with respect to the mean, is most likely a function of lack of milling capacity at the sugar mills. Given that most sugar cane in Eswatini is produced in a relatively small area, the optimal harvest time for producers is highly correlated. As such, mills cannot process all the cane at once, and since sucrose content decreases the moment the cane is harvested, many producers must wait for a harvest date given by each mill which can cause some producers to harvest earlier than optimal and some to harvest later than optimal.

The average farm size was 105 hectares, with a large standard deviation of 727 hectares. The median is 5.67 hectares, indicating that there are more “small” farms than “large” farms. The largest farm is 11,555 hectares, relatively much larger than the average of 105 hectares. Farm size is classified by the Eswatini Sugar Cane Growers Association as being large when there are over 1,000 hectares harvested, medium when 50-1,000 hectares harvested, and small when less than 50 hectares harvested. Based upon this classification, this dataset includes a total of 454 farms with 74 large farms, 595 medium farms, and 3,509 small farms. In terms of numbers of producers, this would seem to indicate that the sugar industry is predominately made up by small scale farmers.

Descriptive Statistics by District.

Table 2 illustrates the differences between districts with respect to average farm size and number of total producers. Mhlume is the largest district by number of observations with 3,072 followed by Ubombo at 853, and Simunye at 253 (Table 2). In contrast, Table 2 demonstrates that the farm size is much smaller in terms of average hectares harvested in Mhlume (44), than in both Ubombo (177) and Simunye (609).

Descriptive Statistics by Year.

Table 3 indicates that the 2014-2015 growing season has the highest number of hectares harvested and in turn also the highest total tons of cane produced. The lowest volume of production (hectares harvested) was during the 2004-2005 growing season, which was during a drought (Table 3).

Tons of Cane per Hectare Statistics.

There are differences in yields by district with Mhlume, Simunye, and Ubombo producing an average of 80.40, 94.13, and 92.23 TCH, respectively. Figure 1 demonstrates a high level of variation of TCH between years across all of Eswatini. For example, the highest producing year (in regards to TCH) was in 2005-2006 with more than 90 tons of cane per hectare and the lowest producing year was in 2008-2009 at less than 75 tons (Figure 1). Figure 2 indicates that Simunye and Ubombo have a tendency for higher and more stable TCH yields with averages around 90 TCH. Mhlume, in contrast, has a wide variation between years with TCH ranging from 67 to 89 tons, and the highest producing year (2006-2007) does not even reach the mean values of the other two districts, Simunye and Ubombo at 94.13 and 92.23 (Figure 2). Using ANOVA testing within R, it was found that there are significant differences between the districts' TCH means ($P<0.001$). An explanation for this variation could be that out of the 3,072 observations from Mhlume, 2,799 of them are small farms. Small farms are most susceptible to higher yield variation in Eswatini as they are less likely to be able to consistently afford inputs and consulting services which can both enhance and smooth yields over time.

Sucrose Percentage Statistics.

Differences in sucrose percentages across districts were marginal. Across all districts sucrose averaged 14%, with Mhlume averaging 14.29%, Simunye averaging 14.01%, and Ubombo averaging 13.83% (Table 2, Figure 4). Using ANOVA testing within R, it was found that there are significant differences between the districts' sucrose percentage means ($P<0.001$). The average sucrose percentage ranged within 1%, from 13.50-14.50 across Eswatini throughout all eleven growing years (Table 3, Figure 3). Figure 3 does not demonstrate any consistent pattern or trends in changes in sucrose percentage across time.

Temperature and Precipitation Statistics.

The highest maximum daily temperature within Eswatini was recorded in 2015 with a mean of 29.6°C and the lowest maximum daily temperature was in the 2013 growing season with a mean of 28.24℃ (Figure 7). Figure 8 illustrates that across all districts 2015 was the hottest year of maximum daily temperatures (Mhlume: 29.4, Simunye: 29.8, Ubombo: 29.6℃). The minimum daily temperatures within Eswatini ranged between 17.33 in 2013 and 18.48 in 2010 as illustrated in Figure 9. All three districts experienced higher than average minimal daily and average daily temperatures during the 2010 and 2015 growing seasons (Figure 9 and Figure 11). Figure 13 illustrates Eswatini average daily precipitation with the highest level of rainfall at 2.8 mm in the year 2010 and the lowest levels of precipitation were recorded in 2015 at 1.65 mm. Using the critical threshold of exposure above 35℃ Figure 15 high exposure in 2010, 2014 and 2015.

Model 1: Table 4 and 5

Year.

Tables 4 and 5 model the impact of cane age (in months), hectare classification (small; 0-50 hectares, medium; 50-1000 hectares, and large; 1000+ hectares), location (by district) and year of production on TCH and sucrose percentage. The year dummies are included in all regressions from Tables 1-10 to estimate if there are statistical differences in Tons of Cane per Hectare (TCH) and sucrose percentage across years. The presence of significant differences across years suggests that there may be production factors, such as weather, which are exogenous to the producer. Thus, year is used as a proxy for the presence of potential weather impacts upon TCH and sucrose percentage.

Table 4 (Regression 1) indicates that seven of the ten dummy variables for year were significant ($P<0.05$) which would suggest that there is likely some climatic variation driving TCH and sucrose percentage which are explained by these year dummies. Within Regression 2-4 on Table 4, at least 5 years per regression were found statistically significant ($P<0.10$). In Table 5, seven out of ten year dummies are statistically significant (P<0.10) with respect to sucrose content based on the pooled dataset (regression 1). From the statistical significance of the year dummies on TCH (Table 4, regressions 1-4) and sucrose percentage (Table 5, regression 1-4) it would seem likely that both sugar cane TCH and sucrose percentage are affected in some fashion by climatic factors.

Hectare Classification: Small, Medium, Large.

Table 4 also indicates that farm size is a significant factor in TCH. The farm size classification, as given by the Eswatini Sugar Cane Growers Association, is defined as: a small farm being less than 50 hectares, a medium farm between 50-1,000 hectares, and large farm being larger than 1,000 hectares. Pooling all three locations, Table 4 indicates that there is a statistical difference (P<0.01) between small and large farms, with 23.264 TCH less yield on small farms than large farms. From this estimate, small holder farmers harvest 28% of the average less than large farms. When the dataset is broken into growing regions (Mhlume, Simunye and Ubombo) the difference is still significant (P<0.01) across all regions (Table 4, regressions 1-4). There are TCH differences (P<0.05) between medium and large farms in two districts (Simunye and Ubombo, regression 3 and 4) but not within the pooled dataset. Within Table 5, hectare classification is not significant in estimating sucrose percentage across all sizes (small, medium, and large) and districts, except for a difference between large and small farms in Simunye (regression 2, P<0.10). Since robust differences were found between small and large farms, and the Eswatini government is attempting to pull small producers out of poverty, more analysis is warranted on what a “small” farm is given that 50 hectares is only an arbitrary value.

Cane Age.

Table 4 illustrates that the age of the sugar cane (in months) was found to be robustly significant ($P<0.10$) on TCH, within the pooled dataset and the district of Mhlume (regression 1 and 2). While older cane is found to have been associated with a yield reduction given the physiology of plants it would make sense that this is a non-linear function, so age squared was used to test for the non-linear effects of age on TCH and sucrose percentage. Since age squared was a significant variable, it was determined that non-linear effects are present, and thus the marginal effects of age were calculated using Equation 1. Looking at the marginal effects of age squared within Table 4, Eswatini and Mhlume (Regression 1 and 2) experience a decrease in TCH by 0.83 and 1.18 with each additional month, respectively. The average harvest age in Eswatini and Mhlume is 12.17 and 12.05 months, respectively (Figure 5 and 6).

Table 5 indicates that average age of cane is significant ($P<0.01$) within all districts and the pooled dataset (regression 1,2,4) with respect to sucrose percentage, except Simunye. The marginal effect of one month of age is estimated increases of 0.031, 0.038, and 0.078 sucrose percentage for Eswatini, Mhlume and Ubombo, respectively (Table 5, regression 1,2,4).

Model 2: Table 6 and 7

Hectares Harvested.

Hectares harvested indicates the number of hectares harvested by each farmer for each year on a continuous scale. By replacing the hectare classification of “small”, “medium”, and “large” farm with a continuous measurement of farm size by hectares harvested, it was possible to estimate marginal effect of each additional hectare on TCH and sucrose percentage. Replacing the arbitrary “bins” of farm size with the actual continuous variable allows the government of Eswatini more accurately estimate what farm size, and below, should be targeted to help increase yields.

Table 6 (Year, Hectares Harvested, Age, and Age Squared) indicates that total hectares harvested is robust as it was found to be highly significant ($P<0.01$) for TCH across district datasets, except Ubombo, and the pooled dataset (Regression 1-3). The estimates on Table 6 show that TCH will increase by 0.003, 0.002, and 0.005 (0.004%, 0.002%, and 0.006% increase from the average) within Eswatini, Mhlume, and Simunye, respectively (regression 1-3). Table 7 (regression 1-4) shows that hectares harvested is not significant ($P>0.10$) in estimating sucrose content of sugar cane.

Model 3: Table 8 and 9

Hectares Harvested and Hectares Harvested Squared.

Table 8 and 9 continue to include the continuous farm size variable, but tested to see if there was non-linearity in the marginal effect of farm size on TCH and sucrose percentage. Table 8 continues to provide evidence that the larger the sugar cane farm the more TCH, as all regressions are highly significant ($P<0.01$). Looking at the marginal effects of hectares harvested on TCH, it is estimated that with an increase of one hectare, TCH will increase by 0.0171 tons within Eswatini (regression 1), which is a 0.016% increase from the dataset average (83.64 TCH, Table 1). Within the districts (regression 2,3,4), the marginal effect of one more hectare harvested is 0.0446, 0.0176, and 0.0105 more TCH, which is a 0.05%, 0.011%, and 0.011% increase from each districts' average TCH (Table 2). Table 8 provides evidence for an increase in earning simply through producing on more hectares, confirming that TCH within this dataset is impacted by the number of hectares harvested within each farm.

Table 9 illustrates that hectares harvested have significant impact ($P<0.10$) on sucrose percentage in Simunye (regression 3) and is not significant in the other datasets (regression 1,2,4). This demonstrates that farm size does not seem to drive sucrose percentage like it does TCH. This could be explained by the fact that sucrose formation is closely associated with genetic potential and climatic variables, where total yield is also associated with input amounts and timing (endogenous to the producer) along with genetic potential and climatic variables (exogenous to the producer).

The adjusted R squared values for the pooled datasets (regression 1) for Model 2 (Table 6) was 0.085 compared to Model 3 (Table 8) at 0.0912. Adjusted R squared values increased by an additional 0.15, 0.11, and 0.01 on regressions 2-4 within Table 8 compared to Table 6. Looking at the Tables 7 and 9 (regressed on sucrose percentage) the differences between adjusted R squared values are not as large as with the TCH regressions, but this is not surprising as hectares harvested is not significant within Table 7 and is only significant within one regression (3) in Table 9. Table 7 and 9 (regression 1) report adjusted R squares of 0.076. Adjusted R squared values are higher within Table 9 (regression 3 and 4), with an additional 0.005 in Simunye, and 0.002 in Ubombo.

Model 4: Table 10 and 11

Farmer Identifier.

Model 4 (Tables 10 and 11) examines the influence of individual farm management practices on TCH and sucrose percentage by dummying out each individual sugar cane producer across growing seasons (denoted by Farmer ID). There were 317 growers included from Mhlume, 30 from Simunye, and 107 from Ubombo, for a total of 454 total Eswatini sugar cane growers. Appendix 1 and 2 demonstrate that 190 and 165 (Table 10b and Table 11b), out of the 454 producers, were found to be statistically significant (P<0.10, 0.05, 0.01), indicating that TCH and sucrose percentage varied greatly across producers. This could be due to a number of factors, such as the impact of HIV/AIDs on the household’s labor capabilities, inequality of training, and lack of access to production resources, education, etc.

In addition, the relatively high adjusted R squared values confirm the robustness of this factor. Table 11 (regression 1) adjusted R squared values increase between Models 3 and 4 as well, with Table 11 showing 0.231 compared to Table 9 at 0.076. Throughout Regressions 2-4, all of Table 10 adjusted R squared values increased by at least 35% from Table 8, and Table 11 increased by at least 74% from Table 9. The high adjusted R squared values and significant individual coefficients of the unique farmer identifiers demonstrate that the influence of individual farmer's skills, training, and management practices upon sugar cane production is significant. This is could be encouraging news to the sugar cane industry and the Eswatini Government as training and access to inputs could help mitigate the differences in yields between producers, regardless of farm size. Again, this could be reassuring as these models have shown if a producer did well last year they are likely to do well this year. As such, if highly motivated producers can receive extension training and obtain access to inputs consistently then there is hope that inertia will prevail, and they can do well into perpetuity. Differences between producers are likely a function of access to inputs, which was not available in this study, and warrants further research.

Model 5: Table 12 and 13

Previous Years' Performance.

While dummying out each producer increases the model's predictability it leaves little room for policy implications and suggestions moving forward. The producer dummy does not allow for the inclusion of location or farm size, due to the possibility of perfect identification, which are two important policy attributes for the sugar cane industry and the Eswatini government in general. The government and Eswatini sugar industry need to know if there are spatial (district) and size (farm size) components to profitability. Model 5 (Table 12 and 13) attempts to gain the explanatory power of dummying out each producer but also include the spatial and size components which are crucial for policy. As such, each individual producers' previous years' TCH and sucrose percentage are included as an explanatory variable in place of an individual dummy for each producer. The variables, year, cane age, and age squared stay within the model.

Previous Years' Production.

Previous years' sucrose percentage and TCH, was used in place of the individual farmer's ID to provide a more concise measurement for the widespread production variability between growers attributed to farm specific production practices within Table 12 and 13. For TCH the previous years' harvest is significant ($P<0.10$) in all districts (regression 1-4) for estimating the current year's harvest. Table 12 coefficients estimate that previous years' TCH increases the present years' TCH by 0.55 and 0.51 tons within the pooled dataset and Mhlume (regression 1,2) and 0.70 and 0.79 tons within Simunye and Ubombo (regression 3,4). Table 13 illustrates significance ($P<0.10$) significant relationship for estimating sucrose percentage this year based upon the prior year across Regressions 1,2, and 4, with the only exception being Simunye (Regression 3). Thus, the results on Table 12 and 13 are preferred to those on Tables 10 and 11 because they eliminate the need for individual producer dummies but still provide a similar amount of information and allow for policy decisions based on farm size and location to be elicited.

Model 6: Table 14 and 15

Climatic Effects.

Throughout Tables 4 through 12 the fixed effect of each year was used to proxy for potential of a climatic influence on TCH and sucrose variations. Tables 4, 6, 8, 10, and 12 (Regression 1) demonstrate that out of the ten years at least six have significant differences on TCH between years in each model. Tables 5,7,9, and 11 (Regression 1) present at least seven out of ten years of significant differences on sucrose percentage in each model. To more clearly represent the effects of climatic on sugar cane production, weather data was analyzed and included in Table 14 and 15.

For increased precision, critical weather thresholds, as defined by the sugar cane physiology literature, are used within Table 14 and 15 to estimate the effect of climate interactions with sugar cane production which replaces the year proxy. The sugar cane literature states that temperatures above 35℃ are destructive to biomass growth in season 1 (the vegetative stage) (Ebrahim, Zingsheim, El-Shourbagy, Moore, & Komor, 1998; Moore & Botha, 2013).

Time above 35℃ is the calculation of the number of growing degree days at or above this critical threshold. Table 14 shows indicates the negative and statistically significant (P<0.01) impact of temperatures above 35℃ in Eswatini (Regression 1) and in the subset of data, Mhlume (Regression 2). Within Eswatini it is estimated that TCH will decrease by 2.140 tons with an additional degree day above 35℃, which is equivalent to a 2.5% yield loss from the average TCH (83.64) for the pooled datset. Mhlume, the largest district by number of sugar cane growers (320, Appendix 1), expects to lose 2.997 TCH from the one additional degree day above the critical threshold temperature in Eswatini, a 3.5% decrease from the average Eswatini TCH (83.64) and a 3.7% decrease from the Mhlume average TCH (80.39). Within the other two districts, Simunye and Ubombo, Time above 35℃ is not a significant indicator for TCH estimates (Table 14).

Figure 15 illustrates that in 2010, Mhlume, Simunye, and Ubombo were exposed to at least 19% more than the dataset average, 4.07 degree days above 35℃, at 4.83, 5.6, and 6.75 days above 35℃. In the most recent weather data year, 2015-2016, Figure 15 demonstrates 8.35, 9.05, and 9.82 degree days above 35℃, which is a 105%, 122%, and 141% increase from the average degree days for the dataset (4.07 days).

To account for the fact that the literature on sugar cane physiology shows that in the second stage of sugar cane production (sucrose forming stage) that cold temperatures are desirable (as long they are above freezing) the model includes the effect of the minimum daily temperature on sucrose percentage.[2] Further, the literature shows that rain prior to harvest (in the sucrose formation stage) can reduce sucrose percentage by promoting new vegetative growth, thus syphoning energy away from sucrose formation, as well as simply diluting the sucrose percentage. As such, rainfall in the sucrose formation stage was used as an explanatory variable for sucrose percentage at harvest.

Within Regression 2-5, it was found that the average minimum temperature does not have a statistically significant effect on sucrose content in Table 15. In contrast, Regression 1 found average minimum temperature has significant in estimating sucrose content by eliminating the district dummy variables (Table 15). This may be due to the location variables perfectly identifying weather effects and thus shifting the significance from the average minimum temperature variable to the dummy variables.

Precipitation is highly significant ($P<0.01$) for sucrose accumulation in Eswatini (Regression 1) and Mhlume (Regression 2) within Table 15. It is estimated that a one-millimeter change of precipitation will decrease sucrose percentage by 0.01% in both Mhlume and Eswatini. Tables 14 and 15 are ultimately the preferred models in the study. These variables are robust and include climatic data which increases the explanatory power of the models.

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[2] There were no recorded lows below 0°C so in this model the colder, the better with respect to sucrose percentage.

Marginal Effect of Hectares Harvested on Production and Revenue.

Using the regression output from Table 8, Figure 16 demonstrates the marginal effect of hectares harvested on TCH when calculated using Equation 2a[3]. The marginal effect of TCH is calculated by using the coefficient estimates from Model 3 (Table 8, Regression 1) for hectares and hectares squared, with the hectares harvested value (as denoted by H) varying between 0-11,500 hectares (by 100 hectares). The largest farm size within this dataset was a farm of 11,555 hectares, hence allowing for Figure 16 to graph all sizes of farms within this dataset. The estimated change in TCH is added onto the dataset mean Eswatini TCH estimated from Table 8 (Model 3, Regression 1) at 90.52 TCH to graph the Mean TCH on Figure 16. To calculate revenue per hectare (Equation 3), the average sucrose price of 2,569 emalangeni is used and is calculated as the average of sucrose price in Eswatini between 2008-2015.[4] The new calculated mean TCH and sucrose percentage being held constant at 0.140 (the estimated average sucrose percentage from Table 9, Model 3) is used to calculate and graphically represent revenue on Figure 16.

Figure 16 illustrates the marginal effect of farm size on revenue per hectare. The average Eswatini sugar cane producer within this dataset harvests 105 hectares (Table 1), which, according to Figure 16, would be associated with a revenue of 32,858 emalangeni at harvest. Marginal effects remain positive for more hectares until 5,400 hectares harvested (Figure 16). For a comparative sense, the revenue earned from sugar cane production is compared with the Eswatini GDP per capita, which was estimated at 38,888 emalangeni in 2015 (World Bank

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[3] Note: Figure 17. Marginal Effect of Hectares Harvested on Sucrose Percentage included within Figures Section for reference only.

[4] Sucrose in this sense is not sucrose percentage, but rather total sucrose harvested. Thus, it is calculated by multiplying TCH by sucrose percentage.

Development Indicators Database, 2017). From this per capita GDP estimate, Figure 16 calculations estimate that marginal effects would become negative at 5,500 hectares allowing that more hectares would not be beneficial above this size and thus an Eswatini sugar cane grower would be hard pressed to earn even the average per capita GDP as a standard of living.

These estimates are obviously underestimated as this calculation is based only on revenue and does not include cost of production. Thus, the arbitrary value of 50 hectares for a "small" farm may be too small to achieve the average standard of living in Eswatini. The marginal effect of hectares harvested demonstrated in Figure 16 confirm the reality that the smaller farmers in Eswatini appear to have lower TCH than larger farmers. This could be attributed to the fact the larger famers have more access to credit and thus can afford optimal amounts and timing of inputs (which was not modeled here). Larger farmers also have better access to crop dusters to apply growth inhibitors which can increase TCH. Overall, from a TCH standpoint, larger farms appear to have higher TCH. Regardless of the cause Table 8 and 9 and Figures 16 indicate that "small" producers in Eswatini need to be given more attention by the government, the extension service and NGO's if the goal is to lift the agricultural community in Eswatini out of poverty.

Marginal Effect of Cane Age on Production and Revenue.

Figure 18 demonstrates the marginal effect of cane age (in months) on TCH and sucrose percentage when calculated using Equation 1. To calculate the marginal effects on TCH, coefficient estimates from the preferred Model 6 (Table 14) for Age and Age squared are used within Equation 1, with the cane age (denoted as A in Equation 1a) being changed from 0-20. The resulting marginal effect of age on TCH from Equation 1a is added onto the mean Eswatini TCH estimate from Table 14 (Model 6, regression 1), of 81.39 TCH for age of sugar cane (0-20 months) to calculate the Mean TCH graphed on Figure 18. To calculate the revenue effects of age (Equation

3), the average sucrose price, 2,569 emalangeni is used and is calculated as the average of sucrose price for years 2008-2015 (T. Dlamini, personal correspondence, April 9, 2018). Figure 18 uses the mean TCH estimate (based on the effects of increasing cane age) and sucrose percentage held constant at 0.140 (estimated Eswatini sucrose percentage from Table 15, Model 6, regression 1) to calculate and graph the revenue curve.

Figure 19 illustrates how increasing the cane age will impact sucrose percentage when the marginal effect is calculated (equation 1b). To calculate the marginal effects on sucrose percentage, coefficient estimates from Model 6 (Table 14) for Age and Age squared are used within Equation 1b, with the cane age (denoted as A in Equation 1b) being changed from 0-20. The resulting marginal effect of age on sucrose percentage from Equation 1b is added onto the mean Eswatini sucrose percentage estimate from Table 14 (Model 6, regression 1), 14.07%, to calculate the Mean sucrose percentage graphed on Figure 19. Revenue (Equation 3) is calculated with a constant TCH at 81.39 (Model 6, Table 14), the average sucrose price of 2,569 emalangeni, and the new calculated Mean sucrose percentages for each age of cane (Figure 19).

Figure 18 and 19 shows the marginal increase of age and allows for the optimal age of sugar cane for TCH and sucrose percentage to be estimated. According to the age and age squared coefficients derived from Table 14 and 15, TCH is estimated to have positive marginal effects until 12.72 months, and after this threshold, older cane age becomes a negative impact on TCH. At the optimal age, 12.72 months old, TCH is estimated at 95.28 TCH and a revenue of 34,458 emalangeni as illustrated on Figure 18. The estimated optimal age of 12.72 slightly higher, but still representative of the Eswatini actual dataset average cane age, 12.17 months (Table 1).

Sucrose percentage has positive marginal effects until 15.36 months of age, with more months of age having a negative impact on sucrose content within cane after this threshold. At

15.36 months the sucrose percentage is estimated at 14.28% with a revenue of 29,877 emalangeni (Figure 19). Within the dataset from Eswatini producers, the average sucrose percentage is 14.18% for Eswatini with the maximum sucrose percentage reaching 17.47% sucrose content (Table 1). Traditionally, Eswatini sugar cane producer's aim to harvest their cane within 12 months, but the harvest age varies based upon climatic variables, mill processing schedule, and producer ability (N. Dlamini, personal communication, June 12, 2017). The main takeaway from graphing sucrose percentage by age is to understand that these models demonstrate the non-linearity character of age and that there is an optimal harvesting period estimated around 12-15 months of age. Out of the total 4,178 observations in the dataset, 952 observations were harvested between the average cane age of 12.72 and 15.36 months.

Climatic Scenarios

Using the preferred model (6) within Table 14 and 15 (Regressions 1) the impact of various future climatic scenarios on sugarcane producer revenue is calculated. By creating a range of possible climate change scenarios, the goal was to estimate the extent of impact on revenue from both increases and decreases in precipitation and temperature. A new, hypothetical weather dataset was created by adding (and subtracting) 0.5 and 1 degree ℃ to all temperature values within the actual weather data (2008-2016) and then re-calculating the degree day summations over the 35℃ threshold and the new average daily minimum temperatures. To calculate precipitation changes, actual rainfall data from 2008-2016 was altered by increasing and decreasing precipitation by 2.5%, 5.0%, and 10.0%, respectively.

Within Table 16, the combination of temperature and precipitation effects on revenue, through changes in TCH and sucrose percentage, was calculated simultaneously. The original estimated revenue (derived from Model 6, regression 1) was 29,550 emalangeni based on the average sucrose price of 2,569 E/Ha with 11.50 tons per hectare sucrose produced (TCH: 81.4, Sucrose Percentage: 14.12,). The revenue changes within Table 16 were calculated by adding the absolute change of TCH and sucrose percentage after exposing them to the aforementioned climate changes, to the estimated TCH and sucrose percentage values from Table 14 and 15 (regression 1) to calculate the sucrose produced, which is multiplied by the price to get revenue.

The change in TCH caused by warmer and colder temperature was calculated by taking the difference between the estimated mean TCH 81.395 based on Model 6 (Table 14, Regression 1 estimates) and the calculated estimated mean TCH when using the mean value of degree days above 35℃ in each of the hypothetical temperature change scenarios. The changes in sucrose percentage caused by the increased or decreased temperatures was a function of two climatic variables, precipitation and average minimum temperature. Sucrose percentage changes caused only by the average minimum temperature was calculated by taking the difference between the estimated mean sucrose percentage, 14.07, from Model 6 (Table 15, Regression 1) and the calculated estimated mean sucrose percentage when using the mean value of average minimum temperatures during the sucrose phase of the sugar cane lifecycle for hypothetical temperature change scenario (when no change occurs in precipitation). Sucrose percentage changes caused only by precipitation was estimated by taking the difference between the mean sucrose percentage (14.07, estimated from Model 6, Table 15, Regression 1) and the new sucrose percentage when using the precipitation mean values calculated at increased or decreased levels (from the actual weather dataset mean precipitation, 649.25 mm), while keeping the average minimum temperature in season 2 constant at the actual weather dataset mean of 20.90℃. Sucrose percentage effects from both changes in precipitation and temperature were calculated by taking the difference of the mean sucrose percentage (14.07, estimated from Model 6, Table 15, Regression 1) and the mean sucrose percentage when re-calculated using the mean precipitation value at each scenarios of increases or decreases in precipitation (-10%,-5%,-2.5%, 2.5%,5%, and 10%), while keeping the average minimum temperature values (19.90, 20.40, 21.40, and 21.90 at -1°C, -1/2°C, +1/2°C, and +1°C, respectively) constant at the means when there is only warming scenarios and no change in precipitation.

Both increases and decreases in these factors are pertinent because temperature and precipitation effect biomass growth and sucrose accumulation differently in the two (vegetative and sucrose formation) cane development stages. As critical cane growth occurs during season one, the cane is sensitive to increased temperature changes. Precipitation specifically effects the quality of sucrose content within the second season, with excess rainfall causing low sucrose content (Gowing, 1977, as cited in, Blackburn, 1984).

Table 16 demonstrates that the temperature effects dominate the precipitation effects with respect to revenue. For example, within the first column (-1°C) when precipitation is 10% below the current state, revenue is expected to increase by 1,108 emalangeni per hectare, while a 10% increase in precipitation portrays a small increase of revenue by 831 emalangeni per hectare as well. The linear expectation of a 10% increase in precipitation would be -1,108 emalangeni, the mirror image of the opposite scenario. Instead, the temperature change (in this case cooler) dominates and allows for the combined positive influence on revenue of 831, even with precipitation increased at 10%.

The trend for all scenarios demonstrates lower revenues with higher temperatures and more precipitation. Increased precipitation lends itself to water down the sucrose content. Drought, to some extent, can be mitigated through the irrigation of sugar cane at pivotal points in the plants life-cycle and therefore is outweighed by the negative impact of increased temperature in this example. With temperature held constant, less precipitation in season 2 always increases sucrose percentage, and the reverse is true with more precipitation always decreasing sucrose percentage.[5] This reflects through to grower revenue per hectare on Table 16 within row 1 (-10% precipitation) which is always a higher value than the seventh row, except for when there are no temperature changes (+10% precipitation). Biologically, this pattern makes sense because too much rain within season 2 can dilute the sucrose content, causing a lower sucrose percentage upon harvest, which decreases revenue for the grower. At best, Figure 16 and 17 illustrate that with increased precipitation (10%) the revenue per hectare increases from the average (29,550.42 E/Hectare) by 2.81% (831 E/Hectare change) and at worst decreases by 4.98% (1,471 E/Hectare loss).

TCH is negatively impacted by the warmer temperature scenarios which cause more degree days above the critical threshold 35°C. All cases of warmer temperature, as well as those with no changes in temperature and increased precipitation, cause negative revenue effects (Table 16). Global temperatures are increasing, and even a 1/2°C increase in this estimate can cause losses from 463-731 E/Ha which is a 1.57%-2.48% decrease from the average revenue (29550.42 E/Hectare) (Table 16 and 17).

Table 16 illustrates that if temperatures were to decrease by 1/2 °C, revenue per hectare change would be positive between 471-539 emalangeni per hectare revenue when precipitation stays within 2.5% (more and less) of the present situation which is 1.59-1.83% less than the average revenue (29550.42 E/Hectare) (Table 17). In comparison, the revenue losses are greater when increasing 1/2°C at the same rainfall (+/- 2.5%), with 564-631 E/Ha of losses (11.91-2.14% decrease from the average, Table 17) estimated emalangeni per hectare on Table 16. In the case of

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[5] All sugar cane in Eswatini is irrigated and the assumption is irrigation water will be available when needed.

extreme heat increases (+1℃), it can be expected that an average Eswatini grower will lose up to 1,471 emalangeni per hectare, a 4.98% decrease from the average expected revenue, when the precipitation increases by 10% (Table 17). In the opposite case, revenue was found to increase by 3.75% from the average by earning 1,108 emalangeni per hectare when temperature decreases by 1℃ and precipitation decreases 10%. From these estimates, it is expected that wetter and warmer climates have negative impacts of losses up to 1,471 E/ha for Eswatini growers. These various climate change scenarios help demonstrate how the livelihoods of sugarcane farmers in Eswatini are influenced with even slight changes to rainfall and temperature.

Conclusion

In conclusion, the relationship between farm size and production capabilities was evidenced and explored through several avenues. First, the SSA classification system found significant differences between “small” and “large” farm TCH means (Table 4). Looking at the number of hectares on each farm, there are increasing marginal effects on TCH from adding additional hectares to the farm up to 5,400 hectares (Figure 16). In addition, the individual farmer management and production practices significantly impact the TCH regardless of farm size in Eswatini (Table 11).

The effects of three critical weather variables, time above 35℃, average minimum temperature, and precipitation, within targeted sugar cane growth stages were significant indicators for both TCH and sucrose percentage. The power of these changing weather patterns indicates risks for earning reductions in both physiological growth stages. Hypothetical weather scenarios of changing weather and precipitation demonstrate lower per hectare revenues for sugar cane growers in the face of hotter, wetter circumstances.

Discussion

This study produced several important findings for the sugarcane industry in Eswatini. First, this study found differences between revenue per hectare for small (less than 50 hectares), medium (50-1000 hectares) and large (greater than 1000 hectares) sugar cane farms. Small farms were found to produce less revenue per hectare than medium and large farms. This can be seen as an opportunity for the Eswatini government, extension services, NGO's and sugar cane growing associations to invest in. While input data was not available for this study it can be assumed that small scale producers likely have less access to timely inputs, than those with larger farms. This study's results may also be a manifestation of the effects of HIV/AIDS as output from small farms is more likely to be affected from HIV/AIDS than large farms as small farms rely on family and not hired labor. Extension training and support could be targeted towards smaller farms to increase their productivity per hectare.

A better understanding for production issues, and those specifically affecting smallholder growers, could be gathered through more specific information regarding individual's farming practices. For example, data such as the number and type of workers on the farm, planting and harvesting dates would provide researchers the ability to narrow in on labor, cane age, and mill timing effects. Within this study, the assumption was that all sugar cane was irrigated, and this might not be the case according to the significance of weather elements specifically in Mhlume. Additional information in regard to the irrigation systems and usage on individual farms could also shed light on the potential disadvantage of smallholder farmers for on-demand irrigation due to lack of payment for water and water rights, poor management planning, and governance issues. This input data could also help the government narrow in on what type of training and education would be most effective for increased production for growers.

Second, a large portion of yield variability across the sugar industry is a function of the producer him/herself. The largest explanatory variable for yield was using fixed effects to delineate producers across time. This should be viewed with optimism for the sugar cane industry as it appears that while climate and other exogenous variables contribute to total yield that the producers themselves are the greatest drivers. Thus again, if the Eswatini government, extension services, NGO’s and sugar cane growing associations could invest in training, it could be possible to lower the gap between those farmers who have the highest revenue per hectare and those who have low revenue per hectare. While there are inherent work differences between everyone, it is a safe assumption that those who are well below the average yield (and thus more likely to be food insecure) would have as great as an incentive to work just as hard as someone who has above average yields. If this assumption holds true, then a large-scale extension campaign on best management practices could lift those producers with low yields closer to the median. Assuming that people want to better their livelihoods and are willing to work to accomplish this goal this study’s finding that producers themselves and not exogenous factors drive revenue can be seen as an opportunity for education in best management practices.

Given the recent El Nino drought and extreme heat events this study also set out to model the effects climate on sugarcane production in Eswatini. Given the sensitivity of sugarcane to extreme heat events, above 35℃, in the vegetative stage and increases in average daily minimum temperatures in the sucrose filling stage this study found that small changes (0.5℃) in average daily temperatures from the observed actual temperatures result in large negative revenue implications for sugarcane producers. Changes in temperature were shown to have higher impact on revenue than changes in precipitation across all scenarios. From these results, investments in heat tolerant breeding in sugarcane cultivars may be warranted in the face of a warming world.

This study was the nexus of endogenous and exogenous factors affecting sugarcane production in Eswatini. Optimistically, this study found that the majority of variation in sugarcane revenue is determined by endogenous factors, producers themselves. As such, investment in training and best management practices may help to lift marginalized populations out of poverty. It also appears that a warming environment will have significant effects on the livelihoods of sugar cane producers. These results should be a call to international sugarcane community for increased research and development in heat tolerant sugarcane cultivars.

This research is only one part of a larger effort to develop sustainable sugarcane production in Eswatini. Achieving this goal in the face of climate change requires an integrated approach across economic, agronomic, hydrologic, and other scientific disciplines whose research can be guided by the results provided in this study. Continued observation of the interaction between increasingly variable weather conditions and sugarcane production outcomes will allow refinement and enhancement of this study and provide plant breeders, agricultural policy makers in Eswatini, and private sugar enterprises with important direction for sustaining production and enhancing livelihoods of the poorest of the poor in an increasingly hot future.

Tables[6]

Table 1. Descriptive Statistics (n=4178)

Variable	Mean	Standard Deviation	Median	Min	Max
Hectares Harvested	105.18	726.59	5.67	1.468	11,555.22
Total Tons Cane	10716.49	75948.71	443.09	13.46	1406341
Total Sucrose	1521.6	10849.17	64.37	2.01	205780.2
Sucrose Percentage	14.18	1.08	14.23	1.09	17.47
Average Age	12.17	1.99	11.99	1.54	50.97
Tons of Cane per Hectares Harvested	83.64	29.94	85.94	2.57	479.08
TSH	11.88	4.39	12.17	0.38	70.54

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[6] Within all tables, Marginal Effect of Age and Hectares Harvested reported as:
Marginal effect of Age $= \beta_4 + 2\beta_5 A + \beta_5$, with A: Average Age of 12.2 months and Marginal effect of Hectares = $\beta_6 + 2\beta_7 H + \beta_7$, with H: Average hectares harvested of 105 hectares.

Table 2. Mhlume Descriptive Statistics (n=3072)

Variable	Mean	Standard Deviation	Median	Min	Max
Hectares Harvested	43.78	390.95	4.20	1.83	7785.08
Total Tons Cane	4279.09	38152.75	337.23	13.46	791666.02
Total Sucrose	621.54	5582.19	48.45	2.01	109748.31
Sucrose Percentage	14.29	1.15	14.42	8.22	17.47
Average Age	12.06	1.67	11.96	1.54	34.70
Tons of Cane per Hectares Harvested	80.39	30.61	82.19	2.57	479.08
Tons of Sugar per Hectare	11.55	4.57	11.82	0.38	70.54

Simunye Descriptive Statistics (n=253)

Variable	Mean	Standard Deviation	Median	Min	Max
Hectares Harvested	609.00	2101.72	71.80	4.78	11555.22
Total Tons Cane	65835.00	229512.33	5967.74	242.02	1406341.34
Total Sucrose	9422.62	32923.41	825.12	36.19	205780.18
Sucrose Percentage	14.01	1.01	14.08	8.22	15.76
Average Age	12.30	2.21	12.10	9.37	39.59
Tons of Cane per Hectares Harvested	94.13	23.39	96.17	32.15	167.19
Tons of Sugar per Hectare	13.18	3.35	13.54	0.91	23.14

Ubombo Descriptive Statistics (n=853)

Variable	Mean	Standard Deviation	Median	Min	Max
Hectares Harvested	176.90	797.92	30.20	1.47	8836.13
Total Tons Cane	17552.04	79710.72	2463.68	110.10	812845.78
Total Sucrose	2419.65	11039.37	338.85	16.39	113935.13
Sucrose Percentage	13.83	0.71	13.87	10.90	15.80
Average Age	12.54	2.79	12.17	4.04	50.97
Tons of Cane per Hectares Harvested	92.23	26.69	92.21	19.95	354.11
Tons of Sugar per Hectare	12.70	3.75	12.69	2.62	46.80

Table 3. Descriptive Statistics by Year

Year	Hectares Harvested	Total Tons Cane	Total Sucrose	Sucrose Percentage	Average Age	Tons of Cane per Hectare
2004-2005	68.67	6500.2	925.49	14.13	13.32	89.7
2005-2006	105.87	11245.27	1626.25	14.65	12.22	91.71
2006-2007	111.05	10975.45	1587.78	14.24	12.07	91.5
2007-2008	111.89	11698.23	1671.56	14.02	12.24	77.71
2008-2009	88.24	8950.01	1309.92	14.41	12.08	73.03
2009-2010	120.56	12147.91	1740.14	14.08	11.93	74.45
2010-2011	122.92	11881.59	1649.63	13.93	12.05	76.64
2011-2012	116.7	12327.87	1736.12	14.22	12.09	82.58
2012-2013	71.46	7780.73	1087.88	13.94	12.37	87.55
2013-2014	96.63	9913.59	1370.65	13.98	11.37	84.14
2014-2015	130.45	13102.8	1848.21	14.45	12.11	86.04

Table 4. Model 1a

	Dependent variable: TCH			
	Eswatini	Mhlume	Simunye	Ubombo
	(1)	(2)	(3)	(4)
Simunye	8.137***			
	(1.982)			
Ubombo	10.448***			
	(1.138)			
2005-2006	0.094	1.094	1.471	-5.428
	(2.040)	(2.353)	(6.908)	(4.795)
2006-2007	-0.375	1.381	-10.893	-5.062
	(2.047)	(2.364)	(6.873)	(4.792)
2007-2008	-14.037***	-19.844***	3.062	-1.150
	(2.064)	(2.389)	(7.181)	(4.947)
2008-2009	-18.709***	-19.846***	-14.974**	-16.970***
	(2.438)	(2.893)	(6.739)	(5.706)
2009-2010	-17.881***	-20.193***	-16.202**	-13.857***
	(2.085)	(2.419)	(6.959)	(4.757)
2010-2011	-15.456***	-14.325***	-16.136**	-18.687***
	(2.081)	(2.404)	(7.394)	(5.260)
2011-2012	-9.560***	-8.721***	-12.356*	-14.244***
	(2.057)	(2.388)	(6.814)	(4.682)
2012-2013	-3.238	0.364	-13.936**	-17.467***
	(2.091)	(2.383)	(6.842)	(5.256)
2013-2014	-7.385***	-6.047**	-10.993	-15.976***
	(2.154)	(2.422)	(6.879)	(5.749)
2014-2015	-5.659***	-3.310	-7.204	-15.141***
	(2.094)	(2.399)	(6.953)	(5.029)
Hectare Class: Medium	-12.956***	-7.321	-26.624***	-12.669**
	(3.511)	(7.004)	(4.788)	(4.999)
Hectare Class: Small	-23.264***	-28.225***	-20.649***	-12.556***
	(3.414)	(6.792)	(4.868)	(4.797)
Age	-0.952	2.276*	2.920	0.391
	(0.598)	(1.210)	(2.558)	(1.100)
Age Squared	0.005	-0.142***	-0.063	-0.014
	(0.016)	(0.044)	(0.057)	(0.023)
Marginal Effect of Age	-0.83	-1.1780	1.3802	0.0506
Constant	121.197***	107.682***	98.965***	112.600***
	(6.381)	(11.003)	(24.202)	(13.275)
Observations	4,178	3,072	253	853
R^2	0.104	0.124	0.190	0.068
Adjusted R^2	0.101	0.120	0.143	0.053
Residual Std. Error	28.392 (df = 4161)	28.711 (df = 3057)	21.660 (df = 238)	25.981 (df = 838)
F Statistic	30.334*** (df = 16; 4161)	30.968*** (df = 14; 3057)	3.996*** (df = 14; 238)	4.372*** (df = 14; 838)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 5. Model 1b

	Dependent variable: Sucrose Percentage			
	Eswatini	Mhlume	Simunye	Ubombo
	(1)	(2)	(3)	(4)
Simunye	-0.338***			
	(0.073)			
Ubombo	-0.494***			
	(0.042)			
2005-2006	0.570***	0.648***	0.778**	0.298**
	(0.075)	(0.091)	(0.320)	(0.121)
2006-2007	0.157**	0.080	-0.066	0.473***
	(0.075)	(0.092)	(0.319)	(0.121)
2007-2008	-0.058	-0.197**	0.263	0.352***
	(0.076)	(0.093)	(0.333)	(0.125)
2008-2009	0.350***	0.334***	0.669**	0.411***
	(0.089)	(0.112)	(0.312)	(0.144)
2009-2010	0.016	-0.059	0.357	0.162
	(0.077)	(0.094)	(0.323)	(0.120)
2010-2011	-0.136*	-0.127	0.527	-0.165
	(0.076)	(0.093)	(0.343)	(0.133)
2011-2012	0.149**	0.089	0.613*	0.237**
	(0.075)	(0.093)	(0.316)	(0.118)
2012-2013	-0.173**	-0.196**	0.436	-0.259*
	(0.077)	(0.093)	(0.317)	(0.133)
2013-2014	-0.102	-0.176*	0.366	0.115
	(0.079)	(0.094)	(0.319)	(0.145)
2014-2015	0.361***	0.447***	0.514	0.054
	(0.077)	(0.093)	(0.322)	(0.127)
Hectare Class: Medium	-0.133	-0.044	-0.344	-0.098
	(0.129)	(0.272)	(0.222)	(0.126)
Hectare Class: Small	-0.167	-0.239	-0.409*	0.110
	(0.125)	(0.264)	(0.226)	(0.121)
Age	0.080***	0.234***	-0.129	0.127***
	(0.022)	(0.047)	(0.119)	(0.028)
Age Squared	-0.002***	-0.008***	0.003	-0.002***
	(0.001)	(0.002)	(0.003)	(0.001)
Marginal Effect of Age Squared	0.0312	0.0388	-0.0558	0.0782
Constant	13.638***	12.839***	15.091***	12.360***
	(0.234)	(0.427)	(1.122)	(0.335)
Observations	4,178	3,072	253	853
R^2	0.080	0.067	0.075	0.158
Adjusted R^2	0.076	0.063	0.020	0.144
Residual Std. Error	1.042 (df = 4161)	1.115 (df = 3057)	1.004 (df = 238)	0.655 (df = 838)
F Statistic	22.541*** (df = 16; 4161)	15.669*** (df = 14; 3057)	1.369 (df = 14; 238)	11.239*** (df = 14; 838)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 6. Model 2a

	Dependent variable: TCH			
	Eswatini	Mhlume	Simunye	Ubombo
	(1)	(2)	(3)	(4)
Simunye	13.143***			
	(1.912)			
Ubombo	12.554***			
	(1.121)			
2005-2006	0.256	1.578	2.472	-5.588
	(2.058)	(2.399)	(7.203)	(4.805)
2006-2007	-0.180	1.865	-9.333	-5.219
	(2.065)	(2.411)	(7.158)	(4.802)
2007-2008	-13.879***	-19.225***	5.558	-1.303
	(2.082)	(2.436)	(7.469)	(4.958)
2008-2009	-19.201***	-20.671***	-12.823*	-17.047***
	(2.459)	(2.950)	(7.011)	(5.719)
2009-2010	-17.533***	-19.390***	-14.138*	-13.894***
	(2.104)	(2.466)	(7.242)	(4.768)
2010-2011	-15.180***	-13.350***	-12.661	-18.759***
	(2.099)	(2.450)	(7.670)	(5.272)
2011-2012	-9.244***	-7.931***	-11.304	-14.302***
	(2.075)	(2.434)	(7.104)	(4.692)
2012-2013	-3.153	1.267	-12.859*	-17.627***
	(2.110)	(2.429)	(7.133)	(5.265)
2013-2014	-7.234***	-5.233**	-10.048	-16.117***
	(2.173)	(2.469)	(7.172)	(5.760)
2014-2015	-5.345**	-2.486	-6.087	-15.192***
	(2.113)	(2.446)	(7.249)	(5.039)
Hectares Harvested	0.003***	0.005***	0.002***	0.002
	(0.001)	(0.001)	(0.001)	(0.001)
Age	-0.878	2.438**	2.912	0.389
	(0.603)	(1.234)	(2.668)	(1.103)
Age Squared	0.001	-0.153***	-0.061	-0.014
	(0.016)	(0.045)	(0.059)	(0.023)
Marginal Effect of Age Squared	-0.8536	-1.2952	1.4236	0.0474
Constant	98.287***	80.225***	74.373***	100.315***
	(5.419)	(8.722)	(24.866)	(12.610)
Observations	4,178	3,072	253	853
R^2	0.088	0.089	0.116	0.063
Adjusted R^2	0.085	0.085	0.068	0.049
Residual Std. Error	28.647 (df = 4162)	29.282 (df = 3058)	22.590 (df = 239)	26.035 (df = 839)
F Statistic	26.803*** (df = 15; 4162)	22.898*** (df = 13; 3058)	2.403*** (df = 13; 239)	4.346*** (df = 13; 839)
Note:				$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 7. Model 2b

	Dependent variable: Sucrose Percentage			
	Eswatini (1)	Mhlume (2)	Simunye (3)	Ubombo (4)
Simunye	-0.326***			
	(0.070)			
Ubombo	-0.488***			
	(0.041)			
2005-2006	0.570***	0.653***	0.788**	0.299**
	(0.075)	(0.091)	(0.321)	(0.122)
2006-2007	0.157**	0.084	-0.045	0.475***
	(0.075)	(0.092)	(0.319)	(0.122)
2007-2008	-0.057	-0.192**	0.288	0.357***
	(0.076)	(0.093)	(0.333)	(0.126)
2008-2009	0.349***	0.327***	0.685**	0.427***
	(0.089)	(0.112)	(0.312)	(0.145)
2009-2010	0.018	-0.052	0.382	0.165
	(0.076)	(0.094)	(0.322)	(0.121)
2010-2011	-0.135*	-0.118	0.550	-0.161
	(0.076)	(0.093)	(0.341)	(0.134)
2011-2012	0.149**	0.096	0.622*	0.238**
	(0.075)	(0.093)	(0.316)	(0.119)
2012-2013	-0.173**	-0.188**	0.445	-0.237*
	(0.077)	(0.093)	(0.318)	(0.134)
2013-2014	-0.102	-0.169*	0.377	0.136
	(0.079)	(0.094)	(0.319)	(0.146)
2014-2015	0.362***	0.454***	0.524	0.055
	(0.077)	(0.093)	(0.323)	(0.128)
Hectares Harvested	0.00003	0.0001	0.00004	-0.00001
	(0.00002)	(0.0001)	(0.00003)	(0.00003)
Age	0.081***	0.235***	-0.128	0.124***
	(0.022)	(0.047)	(0.119)	(0.028)
Age Squared	-0.002***	-0.008***	0.003	-0.002***
	(0.001)	(0.002)	(0.003)	(0.001)
Marginal Effect of Age Squared	0.0322	0.0398	-0.0548	0.0752
Constant	13.472***	12.609***	14.719***	12.432***
	(0.197)	(0.332)	(1.107)	(0.320)
Observations	4,178	3,072	253	853
R^2	0.080	0.065	0.068	0.142
Adjusted R^2	0.076	0.061	0.017	0.129
Residual Std. Error	1.042 (df = 4162)	1.116 (df = 3058)	1.006 (df = 239)	0.661 (df = 839)
F Statistic	24.044*** (df = 15; 4162)	16.370*** (df = 13; 3058)	1.331 (df = 13; 239)	10.699*** (df = 13; 839)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 8. Model 3a

	Dependent variable: TCH			
	Eswatini	Mhlume	Simunye	Ubombo
	(1)	(2)	(3)	(4)
Simunye	12.660***			
	(1.907)			
Ubombo	11.703***			
	(1.128)			
2005-2006	0.310	1.383	2.242	-5.424
	(2.051)	(2.380)	(6.981)	(4.791)
2006-2007	-0.198	1.617	-10.802	-5.052
	(2.058)	(2.391)	(6.947)	(4.788)
2007-2008	-13.912***	-19.507***	3.207	-1.110
	(2.075)	(2.416)	(7.262)	(4.943)
2008-2009	-18.978***	-20.311***	-14.141**	-16.691***
	(2.451)	(2.926)	(6.803)	(5.703)
2009-2010	-17.636***	-19.741***	-15.961**	-13.802***
	(2.096)	(2.446)	(7.034)	(4.753)
2010-2011	-15.273***	-13.724***	-14.824**	-18.686***
	(2.092)	(2.430)	(7.453)	(5.256)
2011-2012	-9.304***	-8.272***	-12.215*	-14.244***
	(2.068)	(2.415)	(6.889)	(4.678)
2012-2013	-3.091	0.780	-13.753**	-17.326***
	(2.103)	(2.410)	(6.916)	(5.250)
2013-2014	-7.230***	-5.538**	-10.965	-15.890***
	(2.166)	(2.449)	(6.954)	(5.743)
2014-2015	-5.452***	-2.911	-6.952	-15.172***
	(2.106)	(2.426)	(7.029)	(5.024)
Hectares Harvested	0.014***	0.046***	0.018***	0.011***
	(0.002)	(0.006)	(0.004)	(0.004)
Hectares Harvested Squared	-0.00000***	-0.00001***	-0.00000***	-0.00000**
	(0.00000)	(0.00000)	(0.00000)	(0.00000)
Marginal Effect of Hectares Harvested	0.01370931	0.0445984	0.01760437	0.01051162
Age	-0.922	2.255*	3.050	0.375
	(0.601)	(1.224)	(2.586)	(1.099)
Age Squared	0.003	-0.145***	-0.063	-0.013
	(0.016)	(0.045)	(0.058)	(0.023)
Marginal Effect of Age	-0.8488	-1.283	1.5128	0.0578
Constant	98.303***	80.749***	71.599***	99.486***
	(5.401)	(8.649)	(24.110)	(12.576)
Observations	4,178	3,072	253	853
R^2	0.095	0.104	0.173	0.070
Adjusted R^2	0.091	0.100	0.124	0.054
Residual Std. Error	28.547 (df = 4161)	29.038 (df = 3057)	21.894 (df = 238)	25.955 (df = 838)
F Statistic	27.185*** (df = 16; 4161)	25.385*** (df = 14; 3057)	3.549*** (df = 14; 238)	4.500*** (df = 14; 838)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 9. Model 3b

	Dependent variable: Sucrose Percentage			
	Eswatini	Mhlume	Simunye	Ubombo
	(1)	(2)	(3)	(4)
Simunye	-0.327***			
	(0.070)			
Ubombo	-0.490***			
	(0.041)			
2005-2006	0.571***	0.652***	0.784**	0.296**
	(0.075)	(0.091)	(0.320)	(0.122)
2006-2007	0.157**	0.083	-0.070	0.473***
	(0.075)	(0.092)	(0.318)	(0.122)
2007-2008	-0.057	-0.193**	0.248	0.354***
	(0.076)	(0.093)	(0.333)	(0.126)
2008-2009	0.349***	0.329***	0.663**	0.422***
	(0.089)	(0.112)	(0.312)	(0.145)
2009-2010	0.017	-0.054	0.350	0.164
	(0.077)	(0.094)	(0.322)	(0.121)
2010-2011	-0.136*	-0.120	0.513	-0.162
	(0.076)	(0.093)	(0.341)	(0.134)
2011-2012	0.149**	0.094	0.606*	0.237**
	(0.075)	(0.093)	(0.316)	(0.119)
2012-2013	-0.172**	-0.190**	0.429	-0.242*
	(0.077)	(0.093)	(0.317)	(0.134)
2013-2014	-0.102	-0.170*	0.362	0.132
	(0.079)	(0.094)	(0.319)	(0.146)
2014-2015	0.362***	0.452***	0.509	0.055
	(0.077)	(0.093)	(0.322)	(0.128)
Hectares Harvested	0.0001	0.0003	0.0003*	-0.0002
	(0.0001)	(0.0002)	(0.0002)	(0.0001)
Hectares Harvested Squared	-0.000	-0.00000	-0.00000	0.00000
	(0.000)	(0.00000)	(0.00000)	(0.000)
Marginal Effect of Hectares Harvested	0.0000616	0.0002644	0.0003060	-0.0001537
Age	0.080***	0.235***	-0.126	0.124***
	(0.022)	(0.047)	(0.118)	(0.028)
Age Squared	-0.002***	-0.008***	0.003	-0.002***
	(0.001)	(0.002)	(0.003)	(0.001)
Marginal Effect of Age	0.0312	0.0398	0.606	0.0752
Constant	13.472***	12.611***	14.672***	12.445***
	(0.197)	(0.332)	(1.104)	(0.320)
Observations	4,178	3,072	253	853
R^2	0.080	0.065	0.077	0.145
Adjusted R^2	0.076	0.061	0.022	0.130
Residual Std. Error	1.042 (df = 4161)	1.116 (df = 3057)	1.003 (df = 238)	0.660 (df = 838)
F Statistic	22.547*** (df = 16; 4161)	15.264*** (df = 14; 3057)	1.409 (df = 14; 238)	10.131*** (df = 14; 838)

Note: *p<0.1; **p<0.05; ***p<0.01

Table 10. Model 4a

	Dependent variable: TCH			
	Eswatini	Mhlume	Simunye	Ubombo
	(1)	(2)	(3)	(4)
Simunye	1.289			
	(14.113)			
Ubombo	9.835			
	(13.142)			
2005-2006	-0.422	0.841	2.200	-6.130*
	(1.665)	(1.980)	(4.503)	(3.535)
2006-2007	-0.897	1.082	-9.803**	-5.807
	(1.672)	(1.991)	(4.492)	(3.544)
2007-2008	-15.153***	-20.699***	1.385	-1.616
	(1.687)	(2.014)	(4.738)	(3.659)
2008-2009	-18.266***	-19.775***	-14.429***	-16.712***
	(2.021)	(2.473)	(4.432)	(4.302)
2009-2010	-20.095***	-21.948***	-18.268***	-16.032***
	(1.711)	(2.043)	(4.634)	(3.539)
2010-2011	-17.425***	-16.069***	-17.431***	-20.765***
	(1.706)	(2.030)	(4.933)	(3.920)
2011-2012	-11.193***	-9.551***	-14.933***	-16.950***
	(1.686)	(2.015)	(4.532)	(3.480)
2012-2013	-4.722***	-0.833	-16.746***	-18.438***
	(1.717)	(2.009)	(4.556)	(3.951)
2013-2014	-9.376***	-7.360***	-15.486***	-18.374***
	(1.771)	(2.046)	(4.573)	(4.320)
2014-2015	-7.941***	-4.850**	-11.792**	-19.382***
	(1.719)	(2.025)	(4.631)	(3.746)
Age	-0.667	0.697	1.745	0.236
	(0.505)	(1.087)	(1.701)	(0.829)
Age Squared	0.004	-0.061	-0.040	-0.011
	(0.014)	(0.040)	(0.038)	(0.017)
Marginal Effect of Age	-0.5650484	-0.79934	0.774112	-0.02929
Farmer ID[1]:				
IDM002	-26.107**	-25.949**		
	(10.925)	(11.429)		
Constant	112.304***	105.336***	104.656***	108.925***
	(9.283)	(11.395)	(16.437)	(11.346)
Observations	4,178	3,072	253	853
R^2	0.475	0.448	0.704	0.582
Adjusted R^2	0.409	0.381	0.647	0.515
Residual Std. Error	23.026 (df = 3709)	24.086 (df = 2740)	13.907 (df = 211)	18.595 (df = 734)
F Statistic	7.169*** (df = 468; 3709)	6.706*** (df = 331; 2740)	12.244*** (df = 41; 211)	8.656*** (df = 118; 734)
Note:				*p<0.1; **p<0.05; ***p<0.01

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[1] Complete list of farmer ID's can be found in Appendix 1.

Table 11. Model 4b

	Dependent variable: Sucrose Percentage			
	Eswatini	Mhlume	Simunye	Ubombo
	(1)	(2)	(3)	(4)
Simunye	-0.762			
	(0.582)			
Ubombo	-1.245**			
	(0.542)			
2005-2006	0.582***	0.670***	0.847***	0.355***
	(0.069)	(0.083)	(0.319)	(0.116)
2006-2007	0.146**	0.076	-0.014	0.520***
	(0.069)	(0.083)	(0.318)	(0.116)
2007-2008	-0.064	-0.202**	0.377	0.443***
	(0.070)	(0.084)	(0.335)	(0.120)
2008-2009	0.387***	0.380***	0.701**	0.537***
	(0.083)	(0.103)	(0.313)	(0.141)
2009-2010	0.004	-0.066	0.416	0.224*
	(0.071)	(0.085)	(0.328)	(0.116)
2010-2011	-0.159**	-0.151*	0.600*	-0.071
	(0.070)	(0.085)	(0.349)	(0.129)
2011-2012	0.130*	0.073	0.662**	0.291**
	(0.070)	(0.084)	(0.321)	(0.114)
2012-2013	-0.189***	-0.197**	0.485	-0.203
	(0.071)	(0.084)	(0.322)	(0.130)
2013-2014	-0.146**	-0.215**	0.410	0.190
	(0.073)	(0.086)	(0.323)	(0.142)
2014-2015	0.356***	0.450***	0.532	0.120
	(0.071)	(0.085)	(0.328)	(0.123)
Age	0.087***	0.192***	-0.125	0.161***
	(0.021)	(0.045)	(0.120)	(0.027)
Age Squared	-0.002***	-0.006***	0.003	-0.003***
	(0.001)	(0.002)	(0.003)	(0.001)
Marginal Effect of Age	0.04664446	0.036845	-0.0622546	0.099036
Farmer ID[1]:				
IDM002	-2.350***	-2.349***		
	(0.451)	(0.478)		
Constant	14.215***	13.673***	14.954***	12.033***
	(0.383)	(0.476)	(1.163)	(0.372)
Observations	4,178	3,072	253	853
R^2	0.318	0.317	0.212	0.361
Adjusted R^2	0.231	0.235	0.059	0.258
Residual Std. Error	0.950 (df = 3709)	1.007 (df = 2740)	0.984 (df = 211)	0.610 (df = 734)
F Statistic	3.688*** (df = 468; 3709)	3.846*** (df = 331; 2740)	1.387* (df = 41; 211)	3.513*** (df = 118; 734)

Note: *p<0.1; **p<0.05; ***p<0.01

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[1] Complete farmer ID list can be found in Appendix 2.

Table 12. Model 5a

	Dependent variable: TCH			
	Eswatini	Mhlume	Simunye	Ubombo
	(1)	(2)	(3)	(4)
Simunye	6.105***			
	(1.664)			
Ubombo	4.793***			
	(1.000)			
2005-2006	-46.435***	9.506	-5.378	-123.820***
	(10.653)	(17.581)	(15.103)	(12.433)
2006-2007	-45.929***	10.401	-18.228	-118.558***
	(10.641)	(17.574)	(14.986)	(12.347)
2007-2008	-60.222***	-11.683	4.395	-115.714***
	(10.643)	(17.584)	(14.996)	(12.382)
2008-2009	-57.319***	-1.491	-21.410	-134.355***
	(10.701)	(17.642)	(14.925)	(12.551)
2009-2010	-55.138***	-1.324	-14.321	-125.078***
	(10.647)	(17.580)	(14.963)	(12.335)
2010-2011	-51.302***	4.903	-8.162	-126.421***
	(10.648)	(17.593)	(15.075)	(12.428)
2011-2012	-45.385***	10.381	-9.092	-118.164***
	(10.644)	(17.577)	(14.941)	(12.316)
2012-2013	-43.750***	14.429	-11.677	-125.197***
	(10.649)	(17.587)	(14.938)	(12.428)
2013-2014	-51.432***	3.877	-9.214	-121.472***
	(10.655)	(17.568)	(14.938)	(12.526)
2014-2015	-47.816***	8.856	-6.060	-125.384***
	(10.647)	(17.581)	(14.963)	(12.383)
Previous Year's TCH	0.558***	0.512***	0.770***	0.793***
	(0.014)	(0.016)	(0.045)	(0.026)
Age	-0.395	-0.705**	1.815**	-0.087
	(0.250)	(0.308)	(0.869)	(0.415)
Age Squared	0.013**	0.027***	0.022	0.004
	(0.005)	(0.010)	(0.030)	(0.005)
Marginal Effect of Age	-0.0862	-0.0565	0.0225	0.0005
Constant	87.563***	37.719**	5.609	140.196***
	(11.106)	(17.819)	(19.574)	(13.921)
Observations	3,721	2,752	223	746
R^2	0.370	0.331	0.621	0.611
Adjusted R^2	0.367	0.327	0.598	0.604
Residual Std. Error	23.641 (df = 3705)	24.729 (df = 2738)	14.602 (df = 209)	17.176 (df = 732)
F Statistic	144.898*** (df = 15; 3705)	104.014*** (df = 13; 2738)	26.394*** (df = 13; 209)	88.583*** (df = 13; 732)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 13. Model 5b

	Dependent variable: Sucrose Percentage			
	Eswatini	Mhlume	Simunye	Ubombo
	(1)	(2)	(3)	(4)
Simunye	-0.209^{***}			
	(0.072)			
Ubombo	-0.368^{***}			
	(0.043)			
2005-2006	0.740	0.874	0.603	0.568
	(0.463)	(0.779)	(1.084)	(0.463)
2006-2007	0.135	0.102	-0.345	0.660
	(0.463)	(0.779)	(1.077)	(0.460)
2007-2008	0.017	-0.012	0.130	0.502
	(0.463)	(0.779)	(1.076)	(0.461)
2008-2009	0.519	0.607	0.555	0.557
	(0.466)	(0.782)	(1.072)	(0.467)
2009-2010	0.083	0.090	0.216	0.317
	(0.463)	(0.779)	(1.074)	(0.459)
2010-2011	-0.023	0.081	0.367	0.039
	(0.463)	(0.780)	(1.080)	(0.463)
2011-2012	0.293	0.308	0.460	0.492
	(0.463)	(0.779)	(1.072)	(0.459)
2012-2013	-0.073	0.003	0.280	-0.077
	(0.463)	(0.780)	(1.072)	(0.463)
2013-2014	0.039	0.044	0.244	0.452
	(0.464)	(0.779)	(1.072)	(0.467)
2014-2015	0.532	0.718	0.355	0.282
	(0.463)	(0.779)	(1.073)	(0.461)
Previous Year's Sucrose Percentage	0.261^{***}	0.286^{***}	0.057	0.236^{***}
	(0.016)	(0.019)	(0.069)	(0.036)
Age	0.029^{***}	0.009	-0.058	0.093^{***}
	(0.011)	(0.014)	(0.062)	(0.016)
Age Squared	0.0002	0.001	0.003	-0.0001
	(0.0002)	(0.0004)	(0.002)	(0.0002)
Marginal Effect of Age	0.0347	0.0219	0.0225	0.0914
Constant	9.981^{***}	9.766^{***}	13.186^{***}	9.063^{***}
	(0.537)	(0.834)	(1.637)	(0.744)
Observations	3,721	2,752	223	746
R^2	0.140	0.134	0.066	0.204
Adjusted R^2	0.137	0.130	0.007	0.190
Residual Std. Error	1.029 (df = 3705)	1.096 (df = 2738)	1.048 (df = 209)	0.639 (df = 732)
F Statistic	40.341^{***} (df = 15; 3705)	32.503^{***} (df = 13; 2738)	1.128 (df = 13; 209)	14.423^{***} (df = 13; 732)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 14. Model 6a

	Dependent variable: TCH				
	Pooled Dataset (1)	Eswatini (2)	Mhlume (3)	Simunye (4)	Ubombo (5)
Simunye		3.226*			
		(1.894)			
Ubombo		3.371***			
		(1.294)			
Hectares Harvested	0.002***	0.002***	0.004**	0.001**	0.002
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
Previous Year's TCH	0.456***	0.445***	0.446***	0.473***	0.395***
	(0.016)	(0.016)	(0.020)	(0.055)	(0.032)
Age	2.588***	2.484***	5.188***	-0.635	1.619
	(0.922)	(0.922)	(1.357)	(7.339)	(1.247)
Age Squared	-0.096***	-0.094***	-0.200***	0.004	-0.032
	(0.029)	(0.029)	(0.046)	(0.256)	(0.034)
Marginal Effect of Age	0.2456	0.1924	0.3151	-0.5380	0.8409
Time above 35C in Season 1	-1.613***	-2.140***	-2.997***	-1.443	-0.435
	(0.560)	(0.594)	(0.816)	(1.805)	(0.837)
Constant	30.224***	32.078***	16.355	55.018	37.352***
	(7.350)	(7.369)	(10.219)	(51.932)	(11.455)
Observations	2,433	2,433	1,752	180	501
R^2	0.267	0.270	0.254	0.335	0.247
Adjusted R^2	0.266	0.268	0.252	0.316	0.239
Residual Std. Error	23.505 (df = 2427)	23.474 (df = 2425)	25.079 (df = 1746)	18.766 (df = 174)	18.272 (df = 495)
F Statistic	177.031*** (df = 5; 2427)	127.966*** (df = 7; 2425)	119.050*** (df = 5; 1746)	17.539*** (df = 5; 174)	32.405*** (df = 5; 495)
Note:					*p<0.1; **p<0.05; ***p<0.01

Table 15. Model 6b

	Dependent variable: Sucrose Percentage				
	Pooled Dataset	Eswatini	Mhlume	Simunye	Ubombo
	(1)	(2)	(3)	(4)	(5)
Simunye		-0.098			
		(0.089)			
Ubombo		-0.328^{***}			
		(0.067)			
Hectares Harvested	-0.00001	-0.00000	0.00001	0.00001	-0.00004
	(0.00003)	(0.00003)	(0.0001)	(0.00002)	(0.00004)
Previous Year's Sucrose	0.230^{***}	0.215^{***}	0.230^{***}	0.131^{*}	0.118^{***}
	(0.020)	(0.020)	(0.023)	(0.073)	(0.045)
Age	0.110^{***}	0.112^{***}	0.090	-0.301	0.307^{***}
	(0.042)	(0.042)	(0.065)	(0.246)	(0.046)
Age Squared	-0.003^{**}	-0.004^{***}	-0.004^{**}	0.011	-0.006^{***}
	(0.001)	(0.001)	(0.002)	(0.009)	(0.001)
Marginal Effect of Age	0.0368	0.0259	-0.0174	-0.0384	0.1672
Average Minimum Temperature in Season 2	-0.189^{***}	-0.073	-0.069	-0.017	-0.037
	(0.045)	(0.051)	(0.069)	(0.102)	(0.070)
Precipitation in Season 2	-0.001^{***}	-0.001^{***}	-0.001^{***}	-0.0004	0.00005
	(0.0002)	(0.0002)	(0.0002)	(0.0004)	(0.0002)
Constant	14.556^{***}	12.288^{***}	12.732^{***}	14.943^{***}	9.991^{***}
	(0.992)	(1.098)	(1.476)	(2.939)	(1.552)
Observations	2,433	2,433	1,752	180	501
R^2	0.083	0.092	0.072	0.034	0.125
Adjusted R^2	0.080	0.089	0.069	0.001	0.115
Residual Std. Error	1.082 (df = 2426)	1.077 (df = 2424)	1.186 (df = 1745)	0.620 (df = 173)	0.686 (df = 494)
F Statistic	36.450^{***} (df = 6; 2426)	30.574^{***} (df = 8; 2424)	22.590^{***} (df = 6; 1745)	1.026 (df = 6; 173)	11.786^{***} (df = 6; 494)
Note:					*p<0.1; **p<0.05; ***p<0.01

Table 16. Revenue change per hectare (SZL E) impact from Climate Change Scenarios[1]

	Temperature Changes in Season 1				
Precipitation Changes in Season 2	-1 °C	-1/2 °C	No Change	+1/2 °C	+1 °C
-10%	1,108.57	642.76	135.82	(463.89)	(1,208.69)
-5%	1,039.36	574.15	67.91	(530.88)	(1,274.39)
-2.5%	1,004.75	539.84	33.95	(564.37)	(1,307.25)
No Change	970.14	505.54	-	(597.86)	(1,340.10)
+2.5%	935.54	471.23	(33.95)	(631.35)	(1,372.96)
+5%	900.93	436.93	(67.91)	(664.84)	(1,405.81)
+10%	831.72	368.31	(135.82)	(731.83)	(1,471.52)

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[1] As derived from coefficients in Table 14 and 15, Regressions 1.

Table 17. Revenue percentage change per hectare impact from Climate Change Scenarios

	Temperature Changes in Season 1				
Precipitation Changes in Season 2	-1 °C	-1/2 °C	No Change	+1/2 °C	+1 °C
-10%	3.75%	2.18%	0.46%	-1.57%	-4.09%
-5%	3.52%	1.94%	0.23%	-1.80%	-4.31%
-2.5%	3.40%	1.83%	0.11%	-1.91%	-4.42%
No Change	3.28%	1.71%		-2.02%	-4.53%
+2.5%	3.17%	1.59%	-0.11%	-2.14%	-4.65%
+5%	3.05%	1.48%	-0.23%	-2.25%	-4.76%
+10%	2.81%	1.25%	-0.46%	-2.48%	-4.98%

Figures

Figure 1. Eswatini TCH (tons)

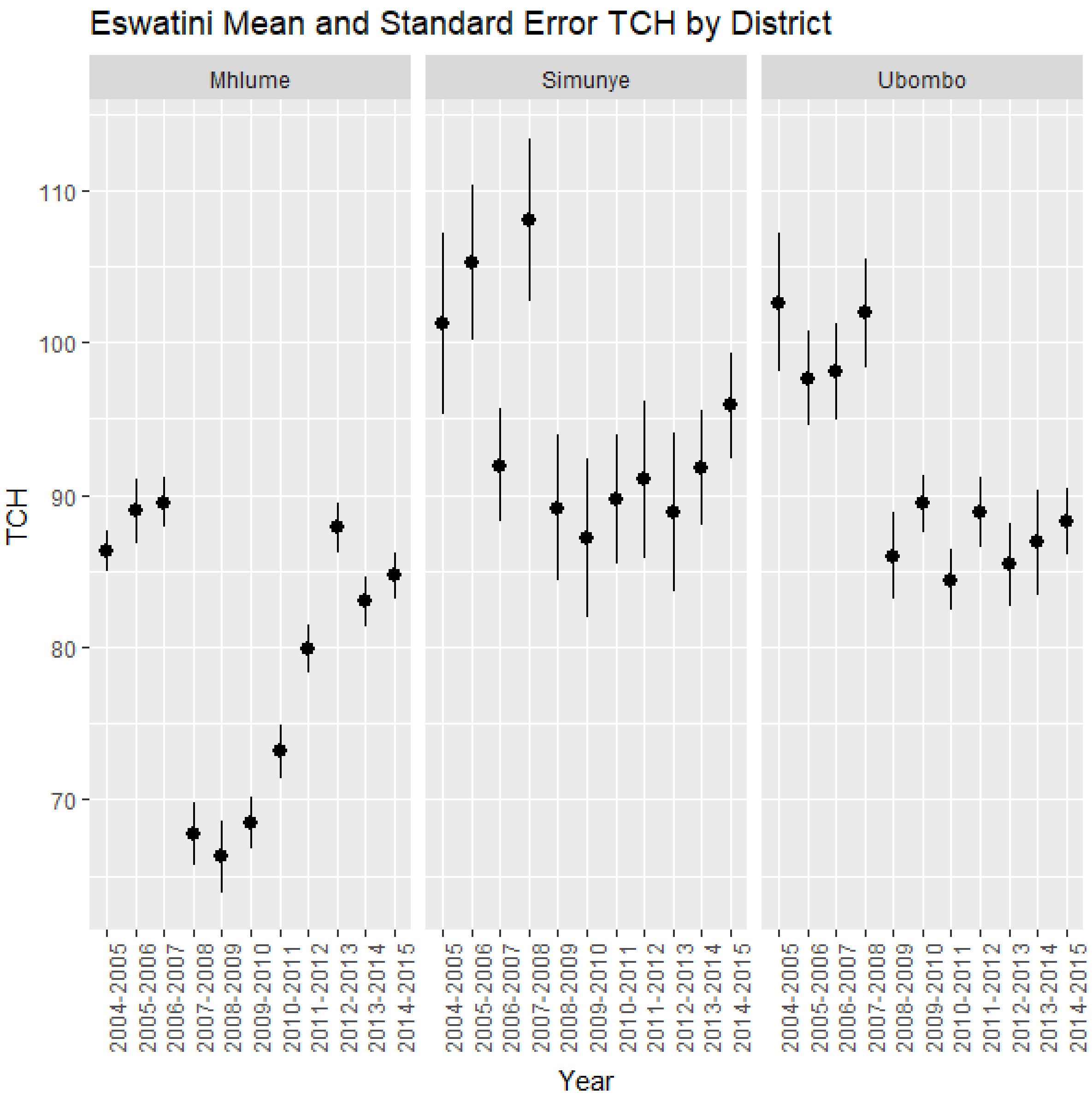

Figure 2. Eswatini TCH (tons) by District (

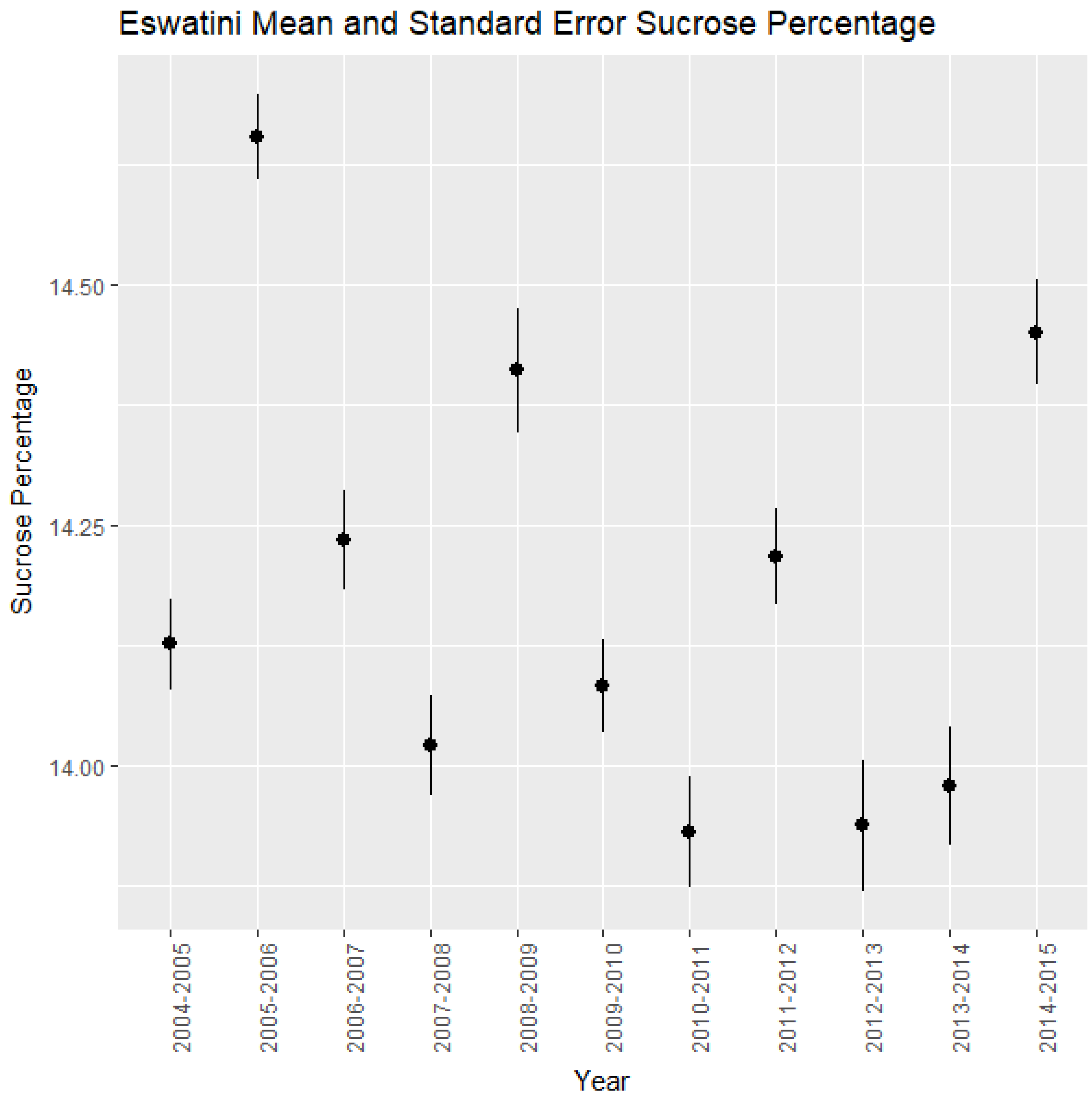

Figure 3. Eswatini Sucrose Percentage

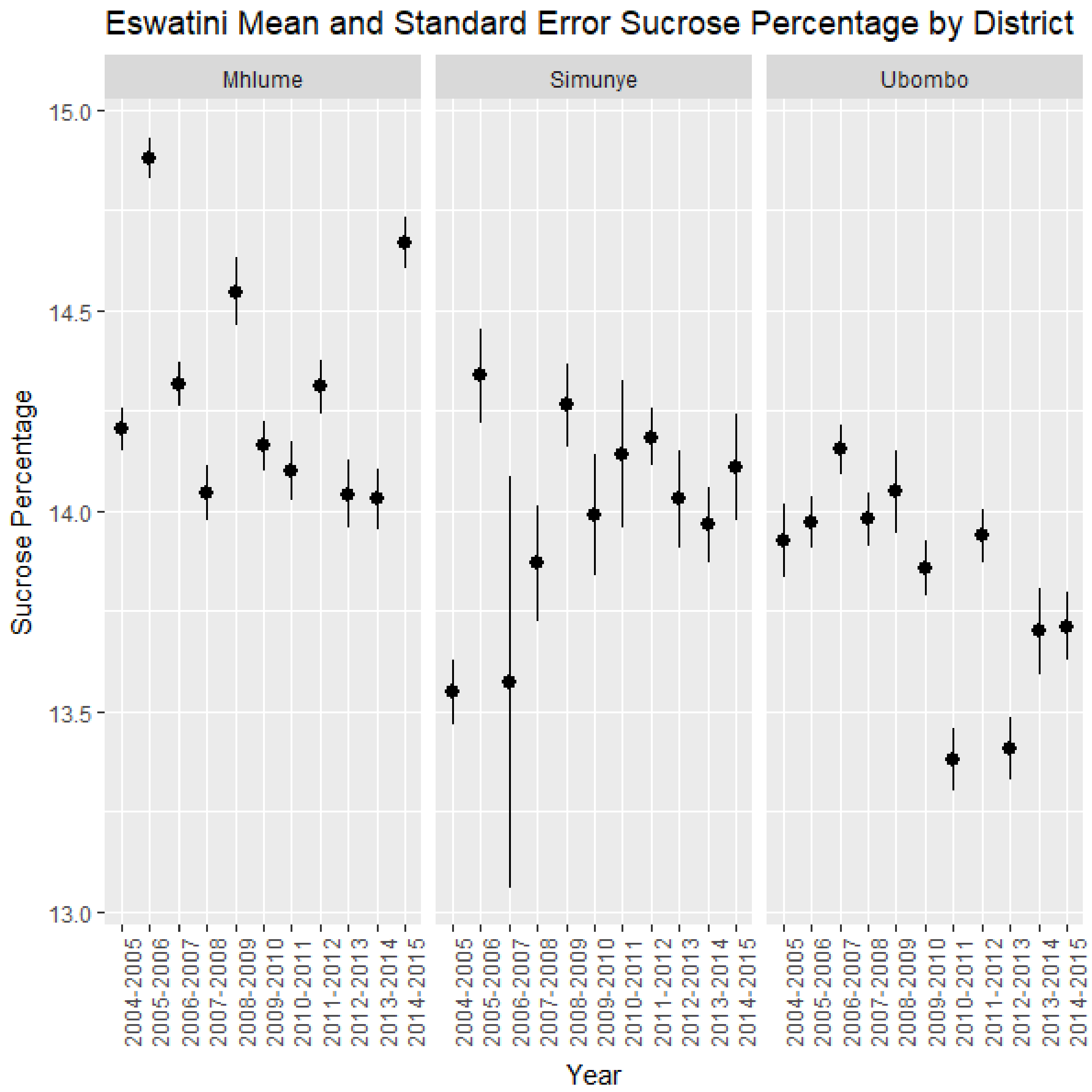

Figure 4. Eswatini Sucrose Percentage by District

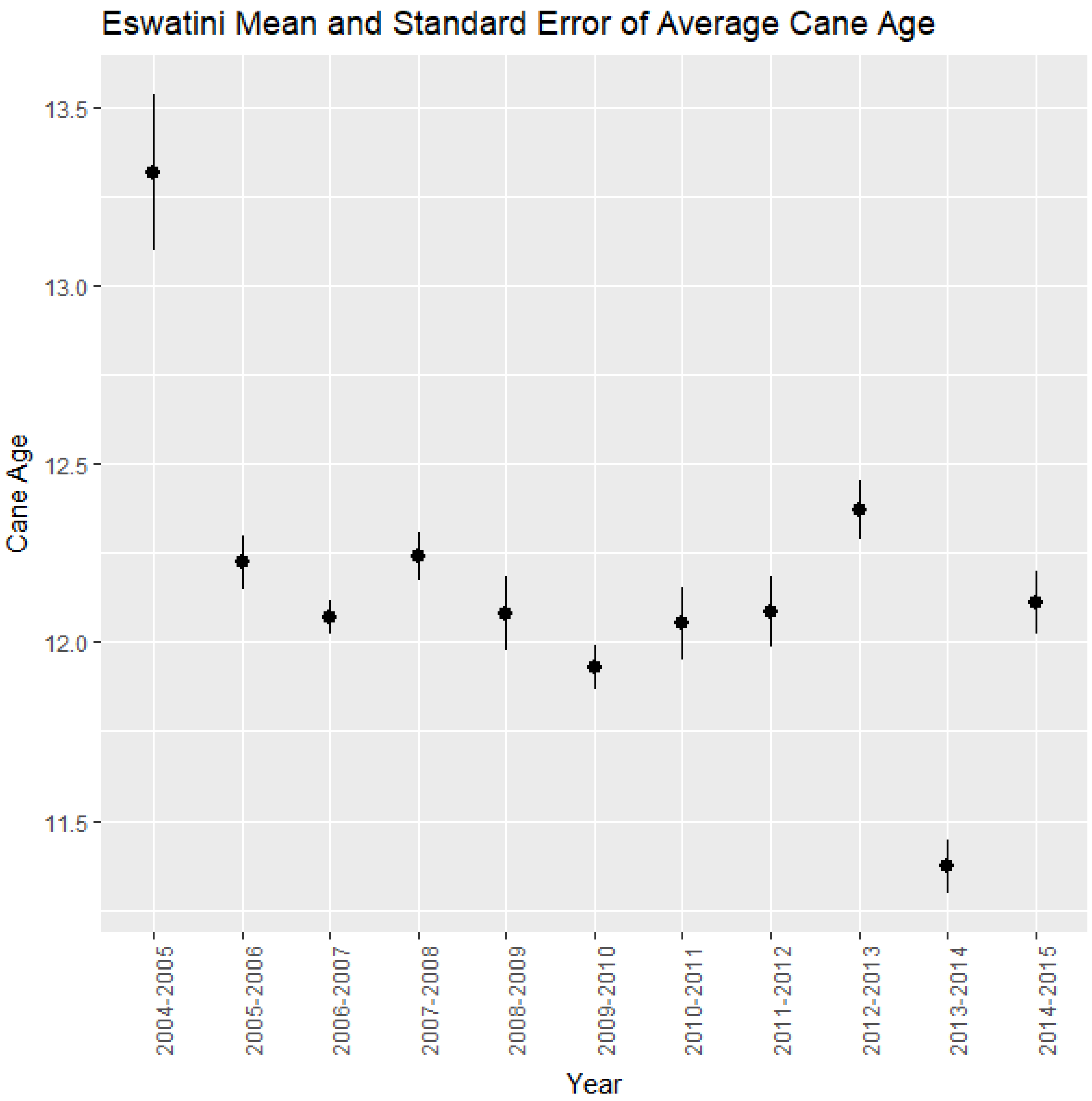

Figure 5. Eswatini Cane Age (months)

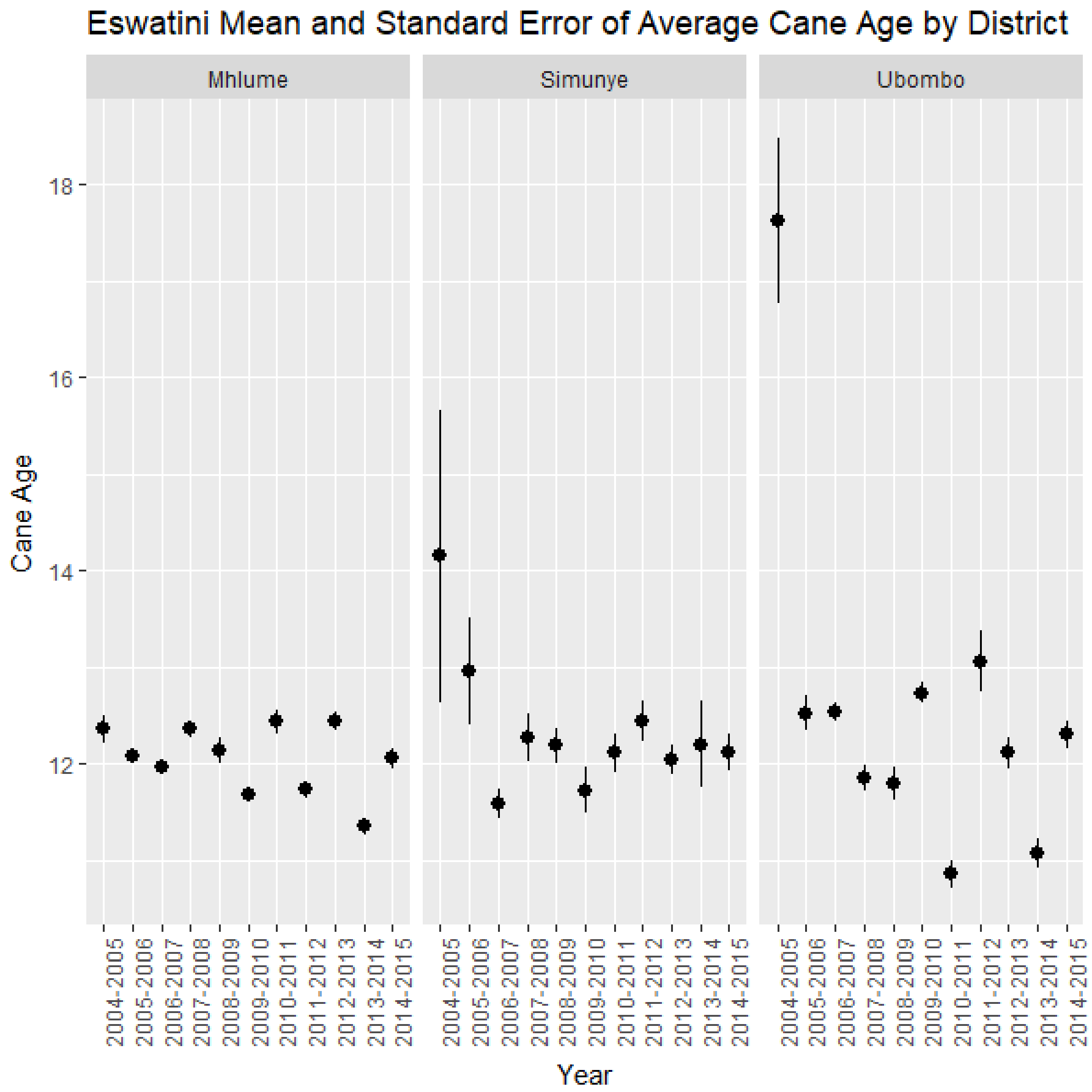

Figure 6. Eswatini Cane Age (months) by District

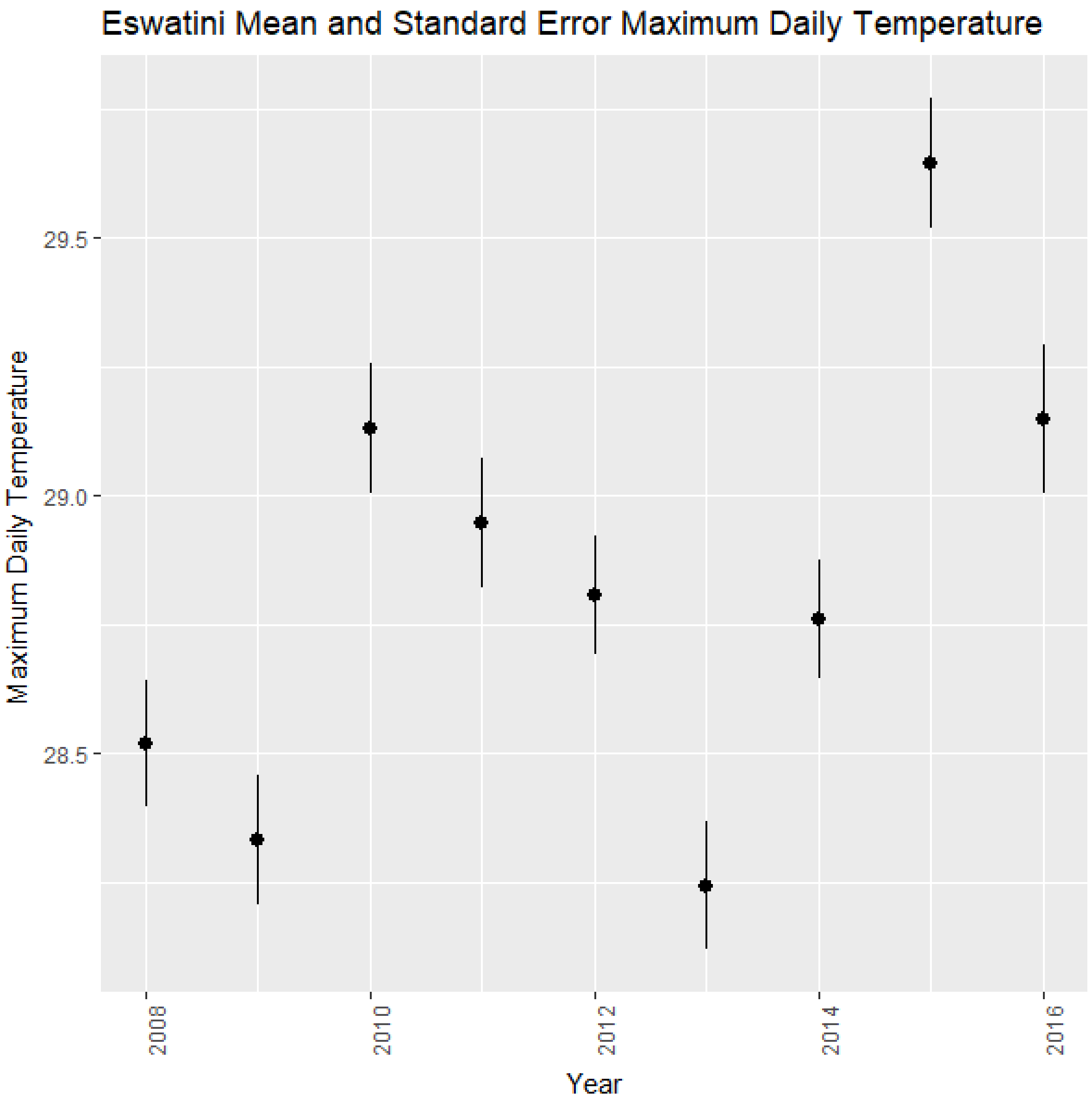

Figure 7. Eswatini Maximum Daily Temperature (℃)

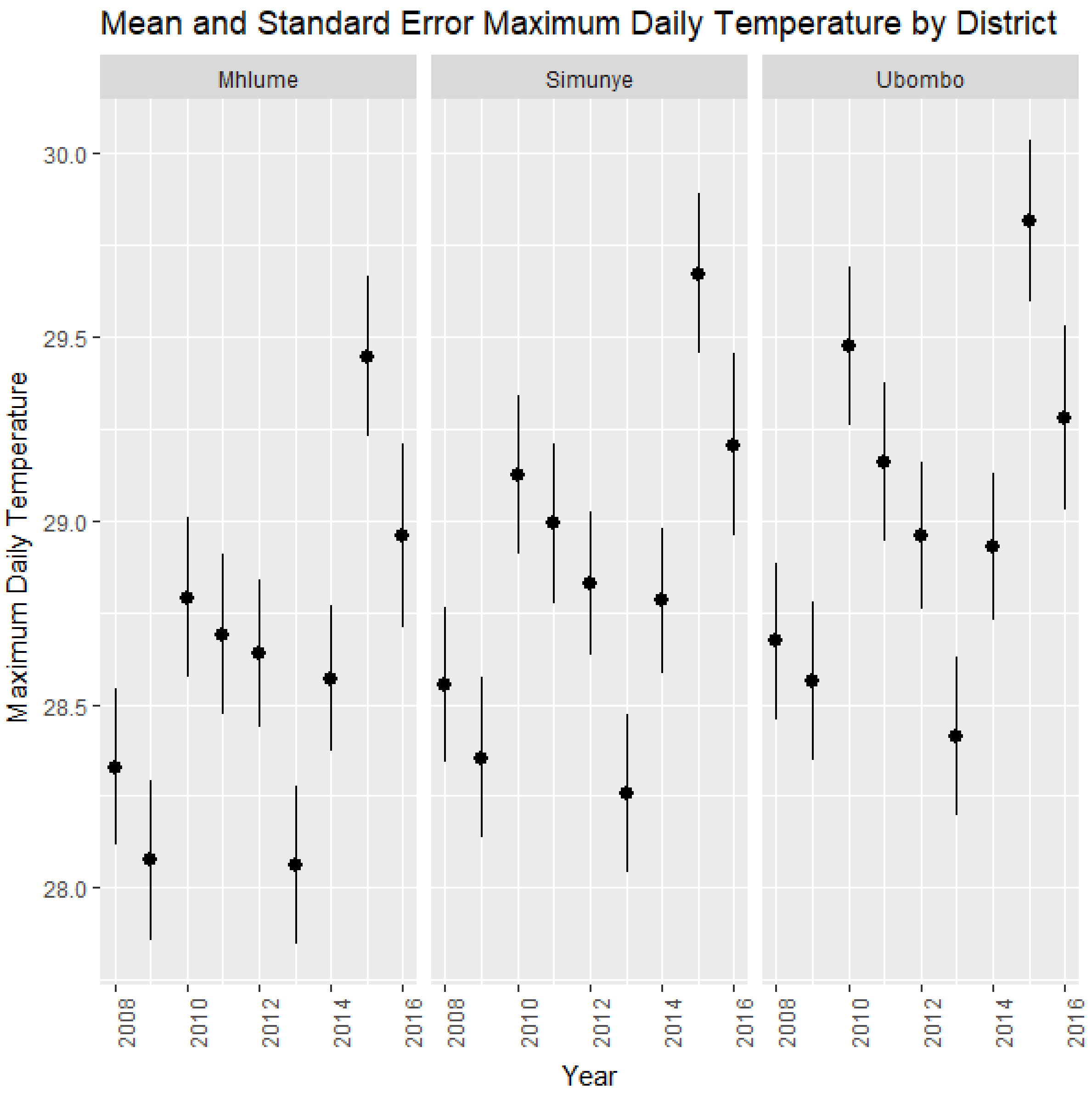

Figure 8. Eswatini Maximum Daily Temperature (°C) by District

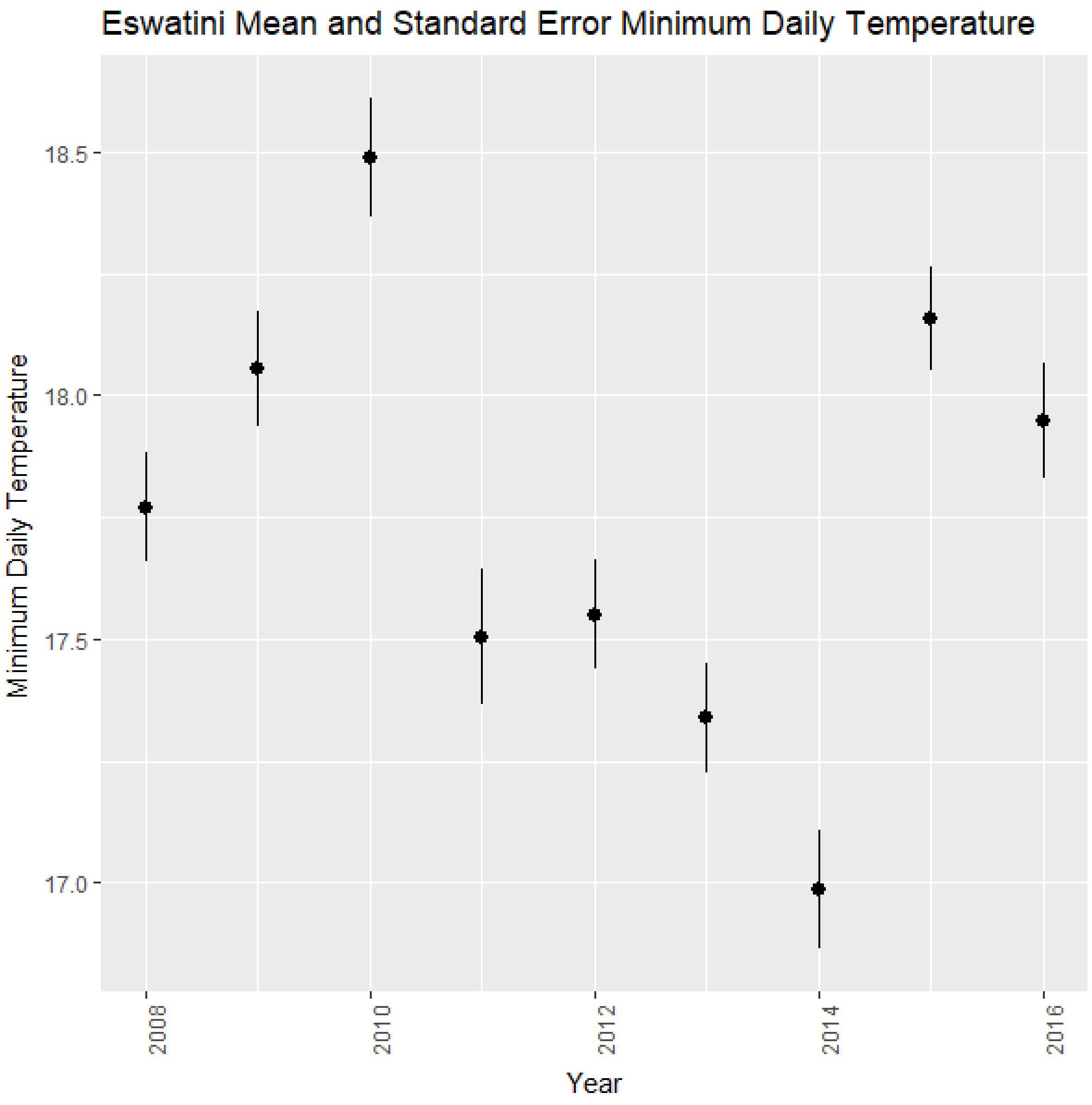

Figure 9. Eswatini Minimum Daily Temperature (℃)

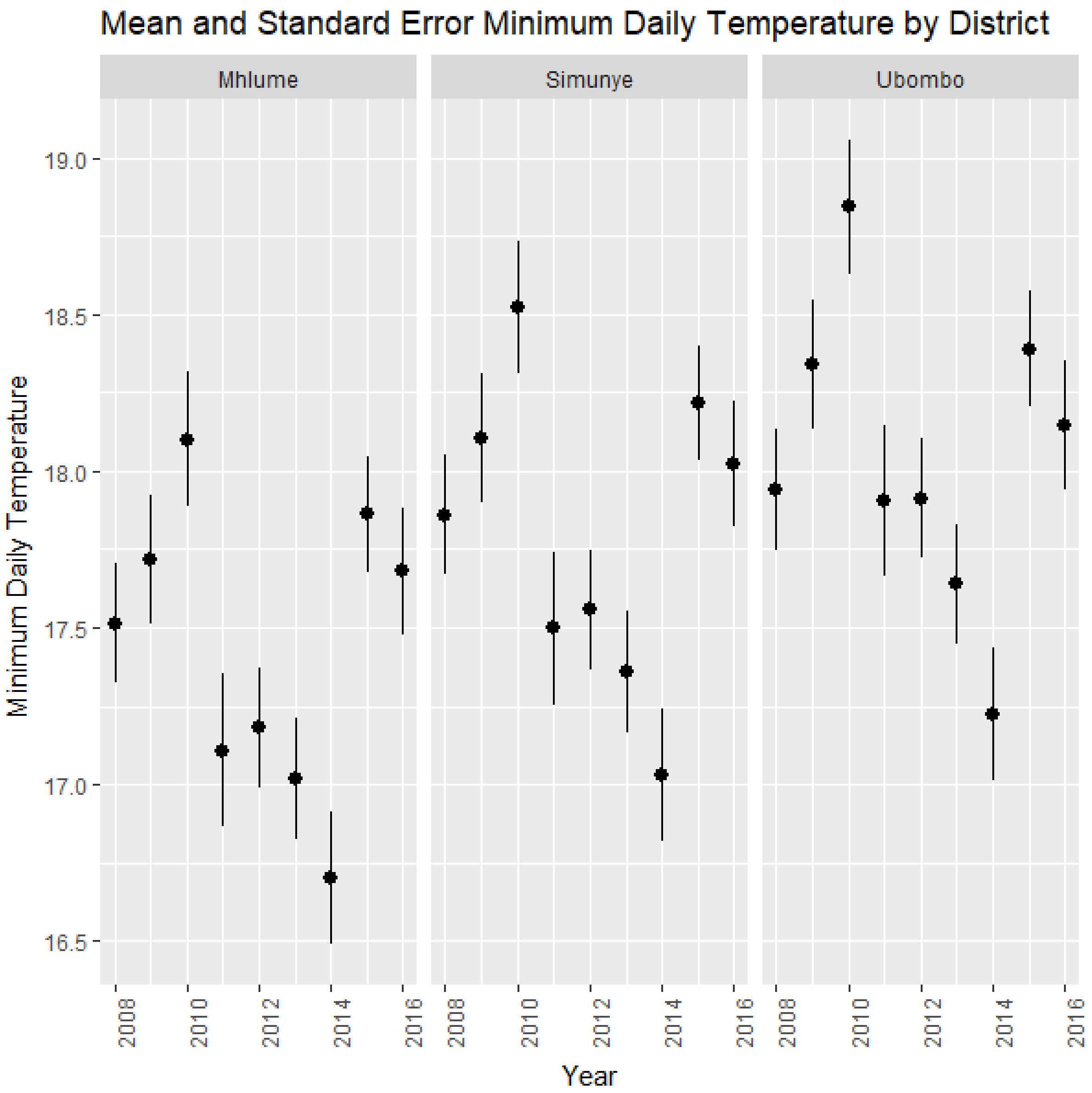

Figure 10. Eswatini Minimum Daily Temperature (℃) by District

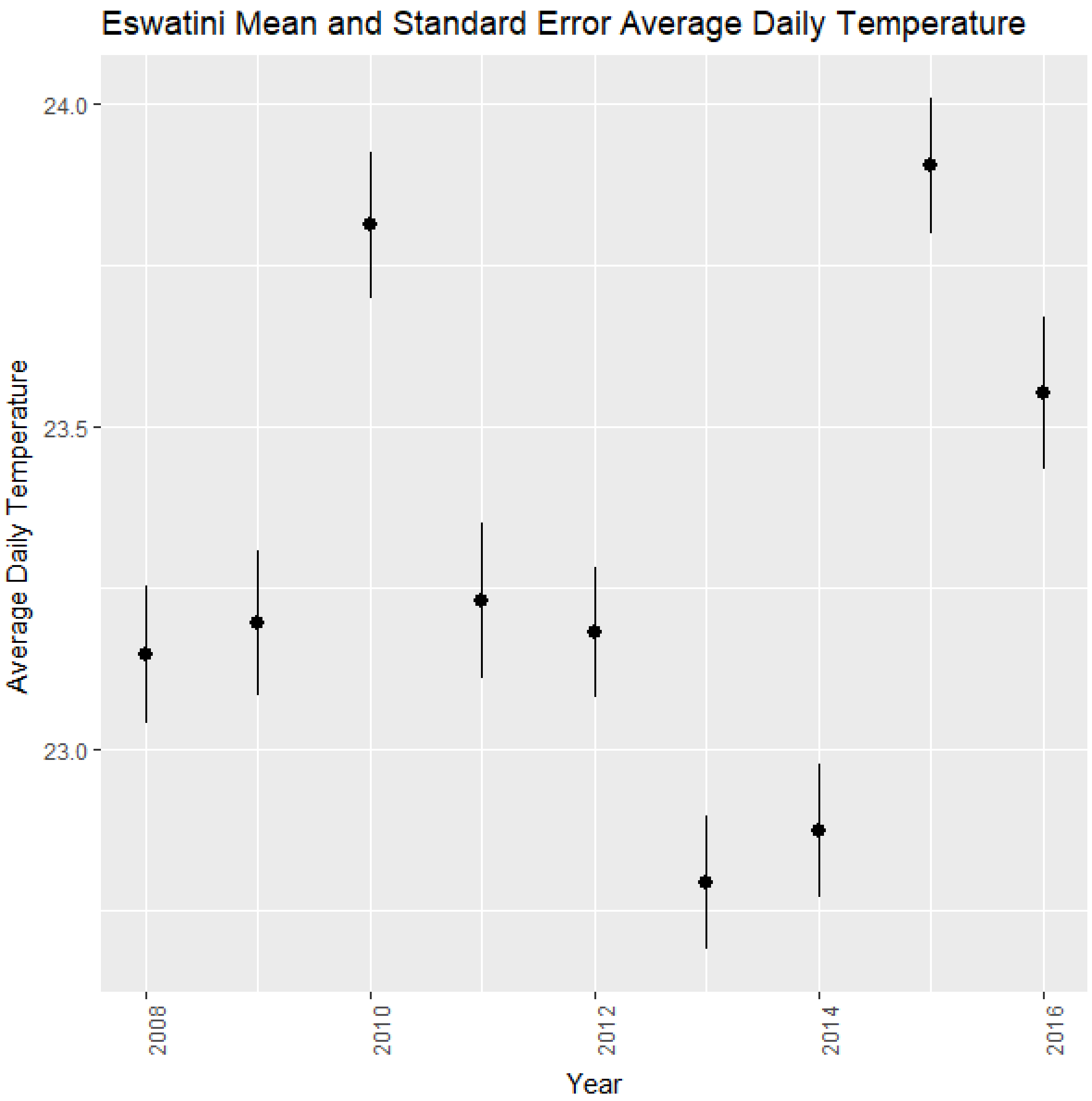

Figure 11. Eswatini Average Daily Temperature (℃)

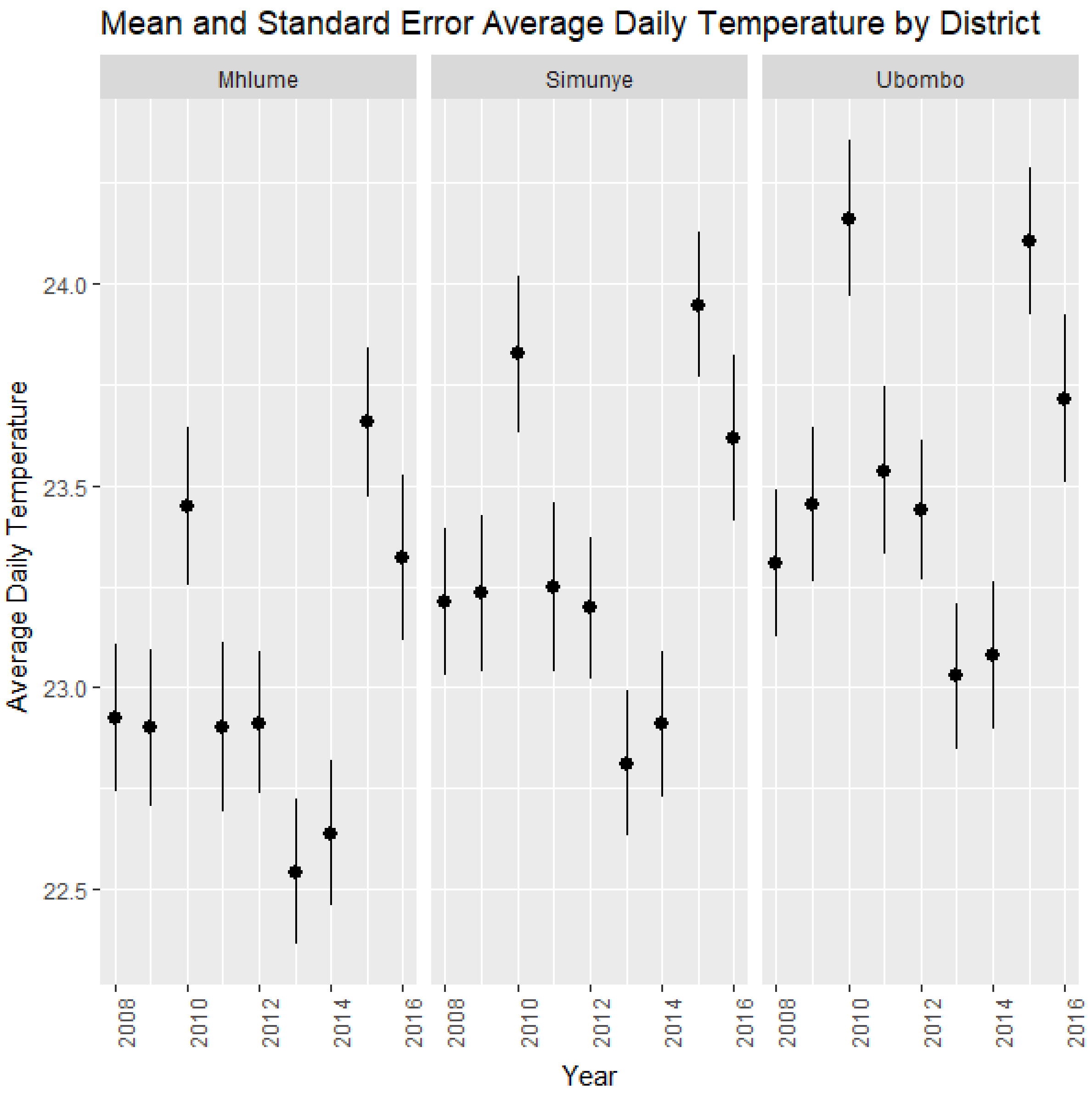

Figure 12. Eswatini Average Daily Temperature (℃) by District

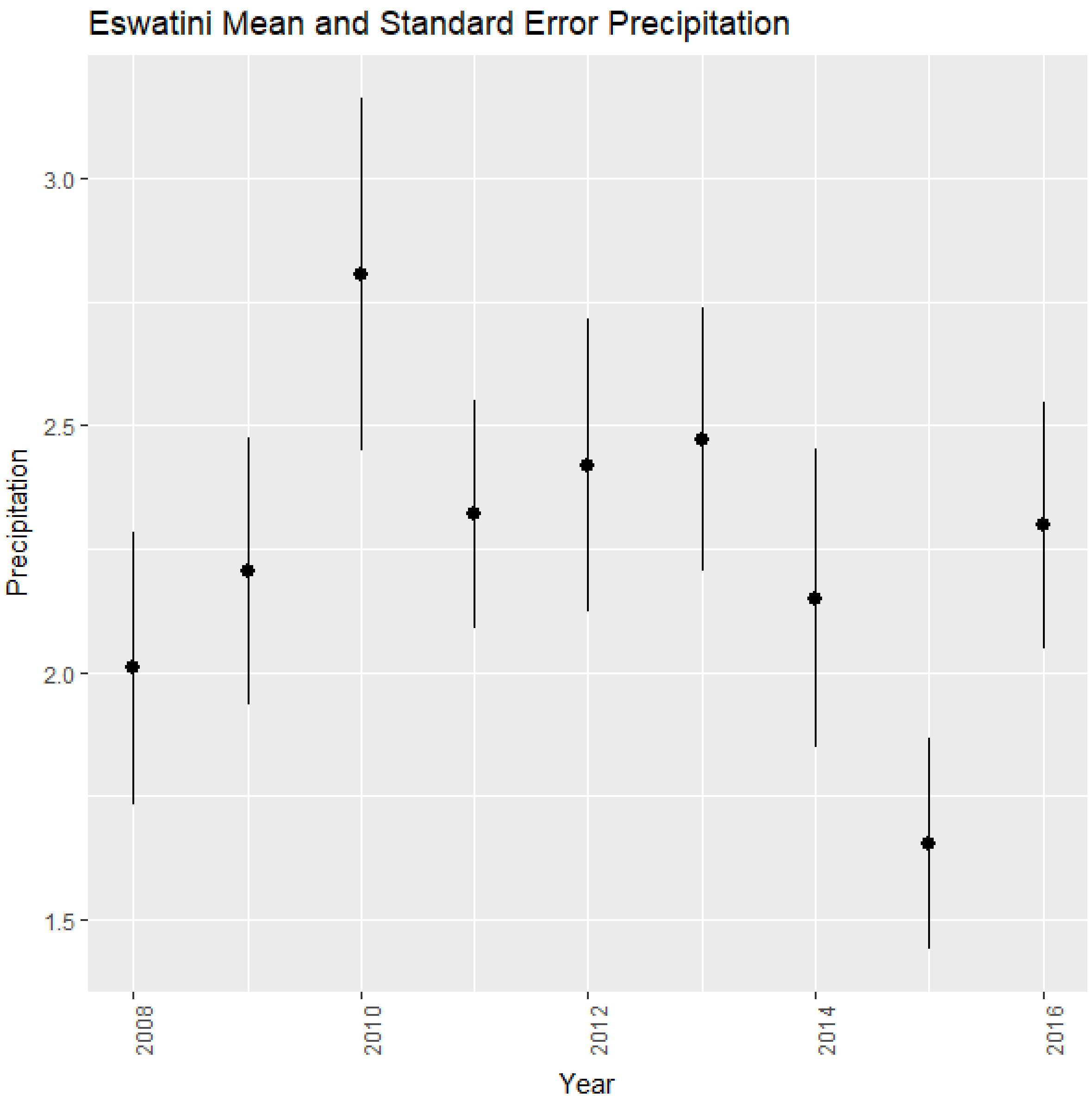

Figure 13. Eswatini Daily Precipitation (mm)

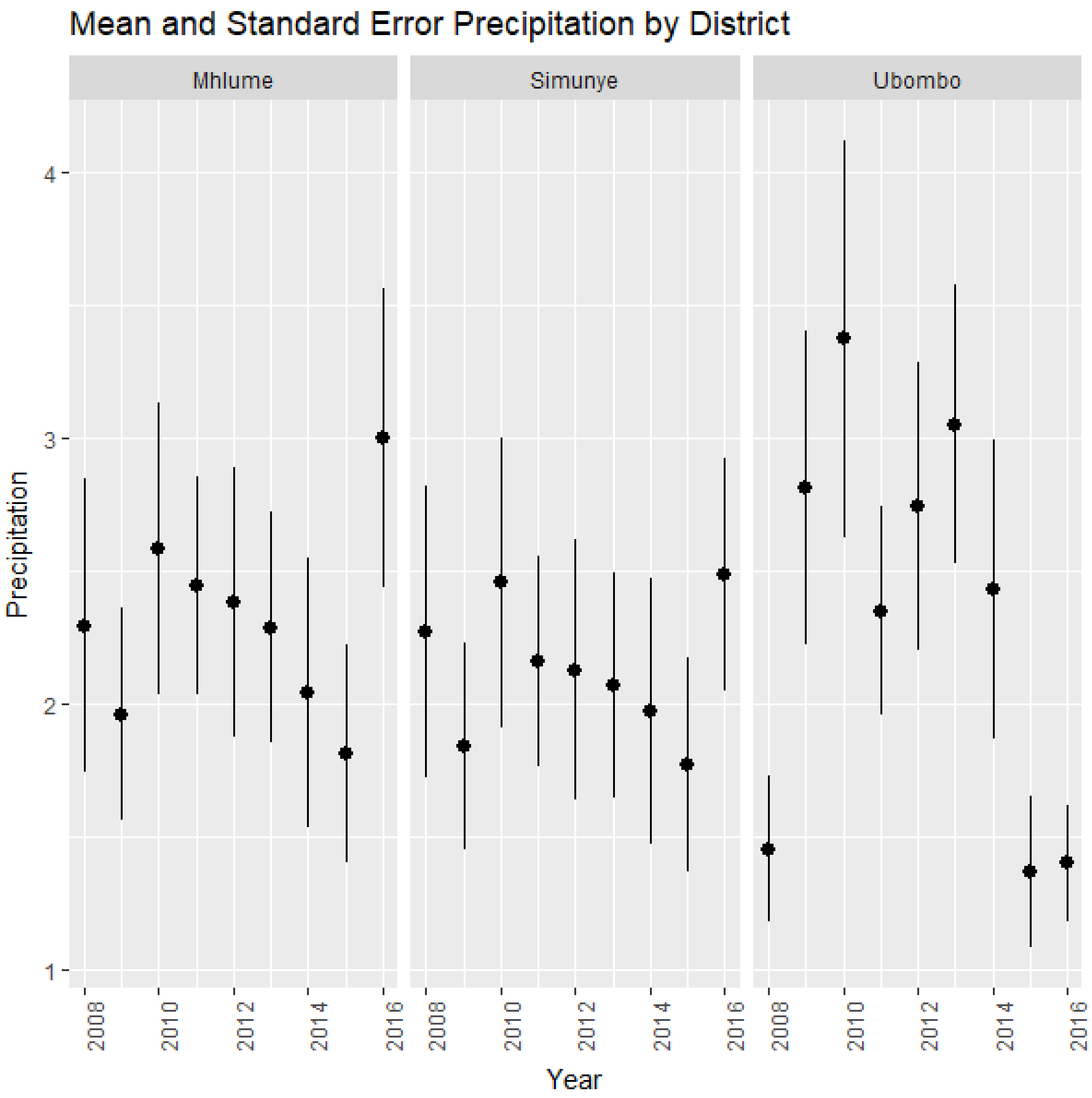

Figure 14. Eswatini Daily Precipitation (mm) by District

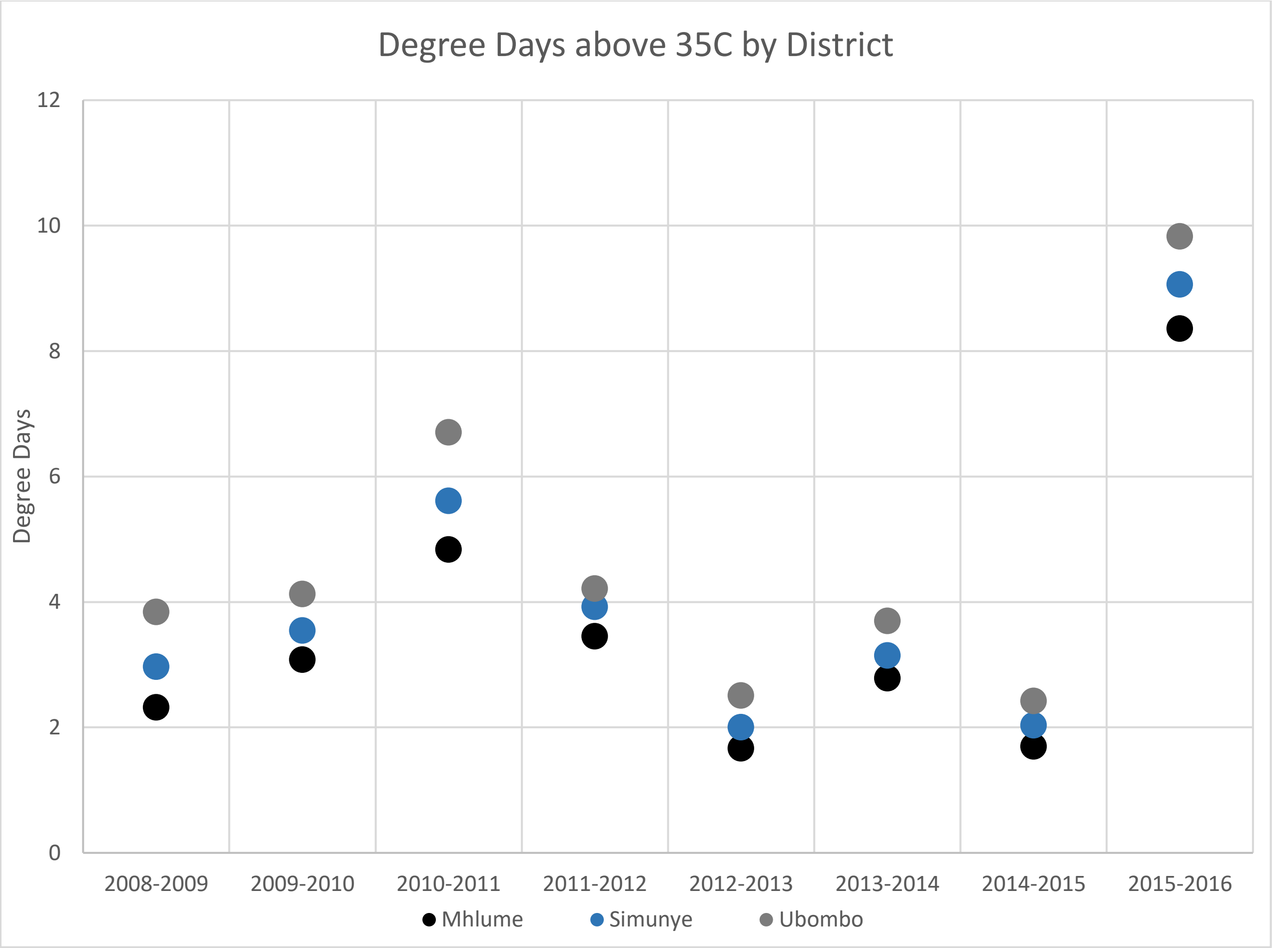

Figure 15. Time (Count of Degree Days) above 35℃

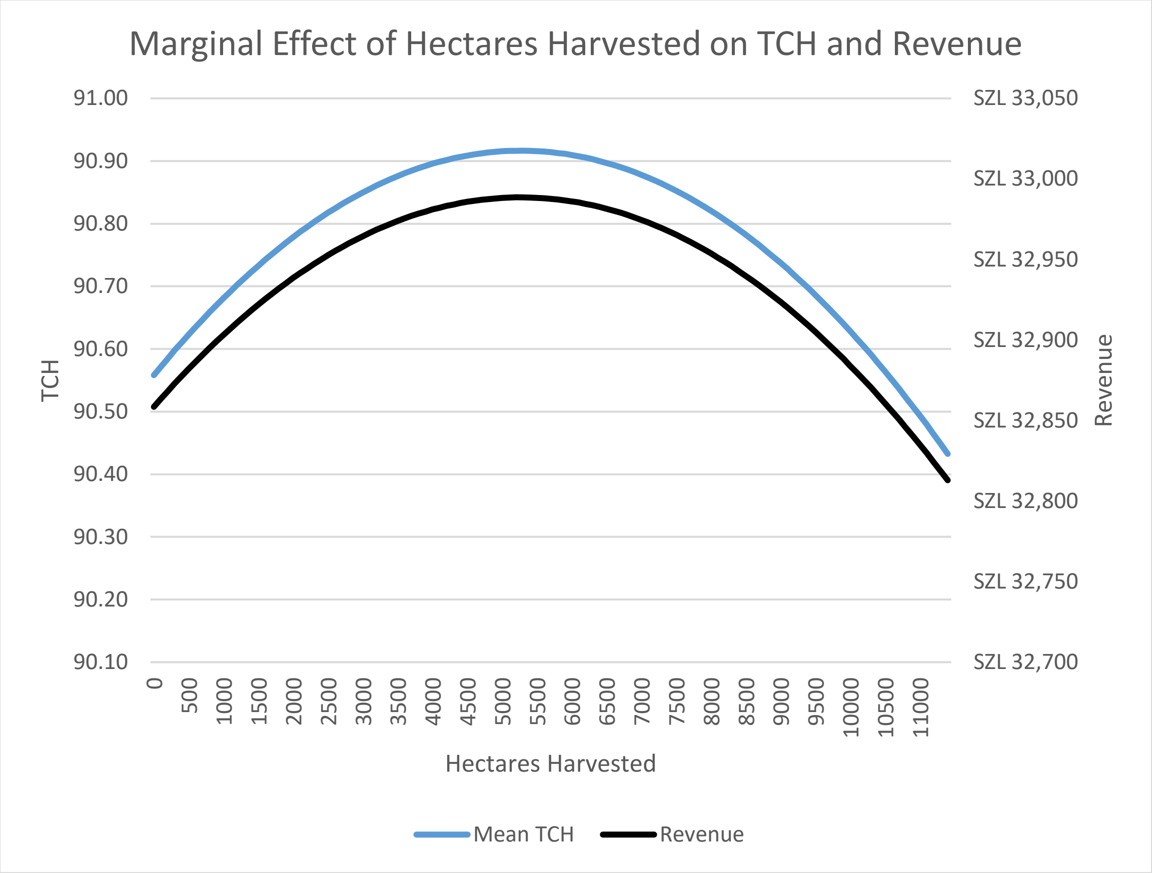

Figure 16. Marginal Effect of Hectares Harvested on TCH (tons) and Revenue (Emalangeni)[1]

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[1] As derived from coefficients in Table 8, regression 1.

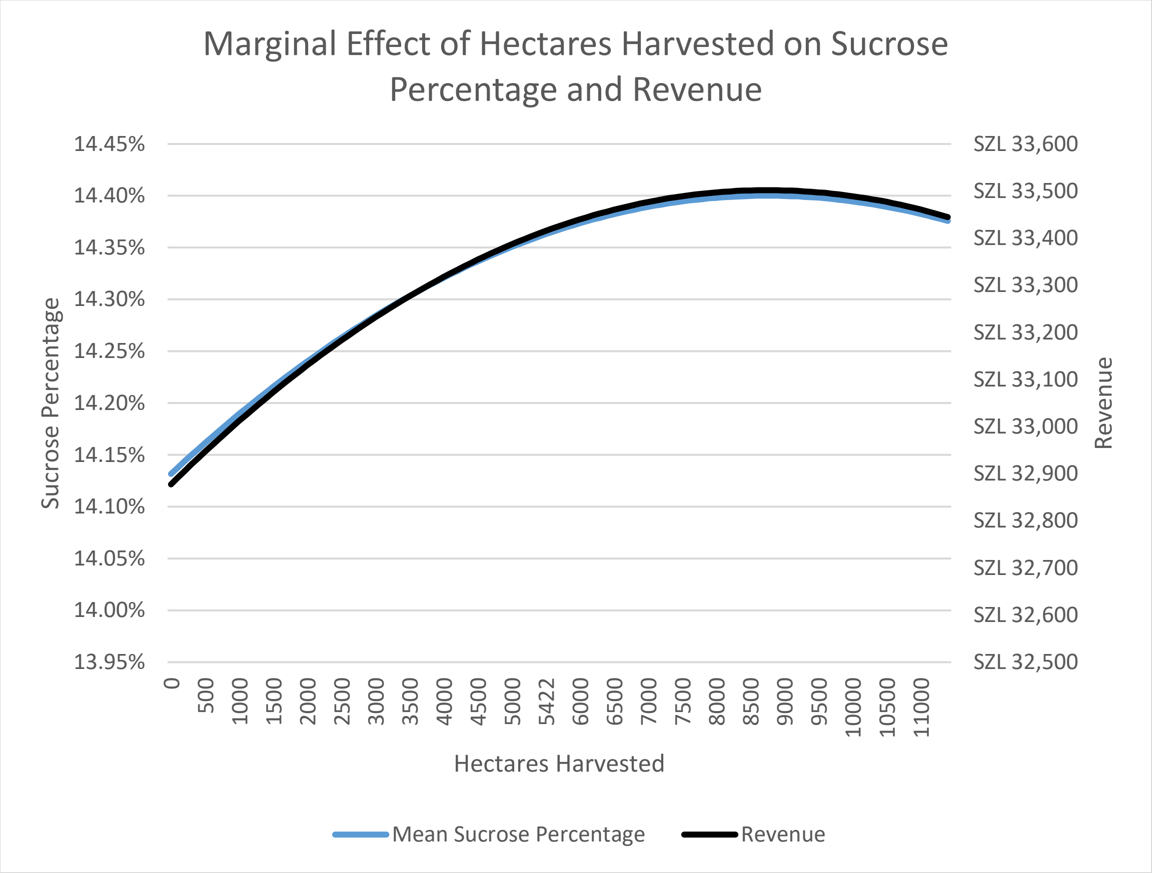

Figure 17. Marginal Effect of Hectares Harvested on Sucrose Percentage and Revenue (Emalangeni)[1]

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[1] As derived from coefficients in Table 9, regression 1.

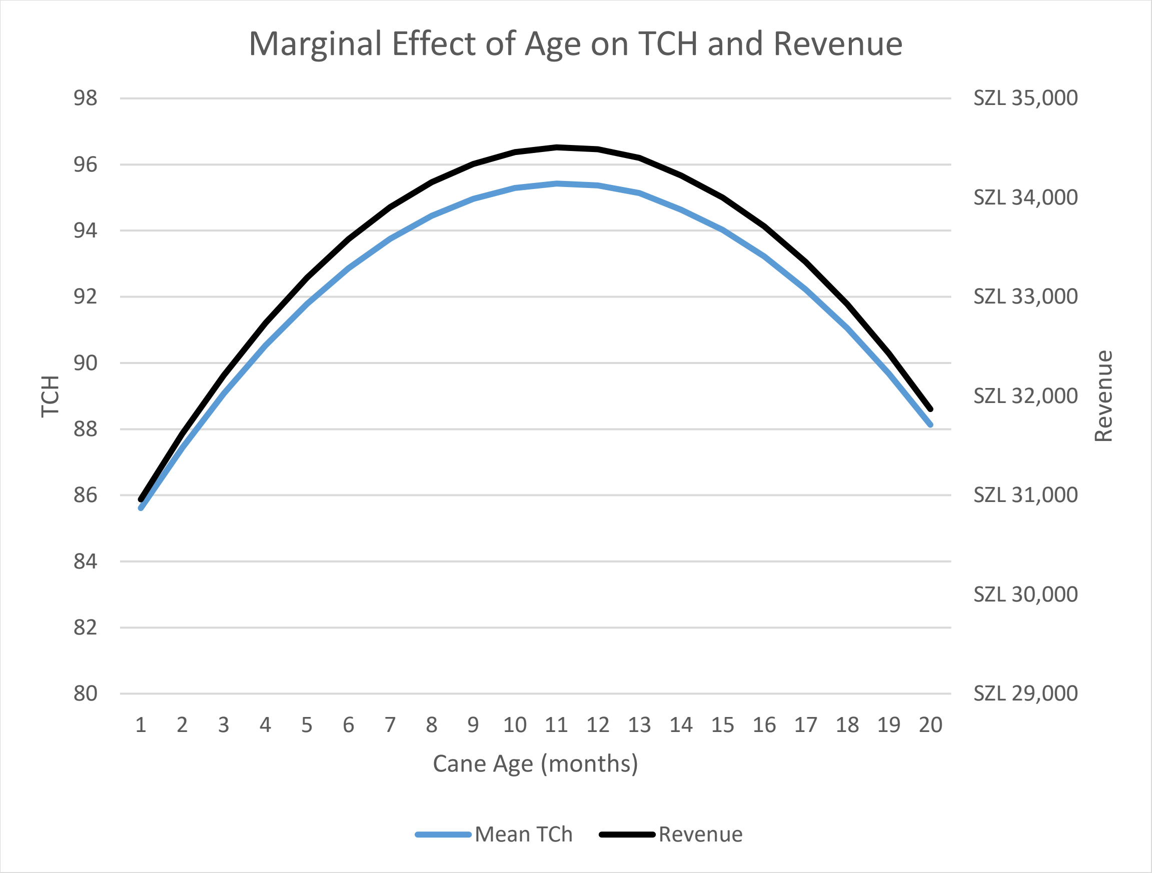

Figure 18. Marginal Effect of Age on TCH (tons) and Revenue (Emalangeni)[1]

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[1] As derived from coefficients from Table 14.

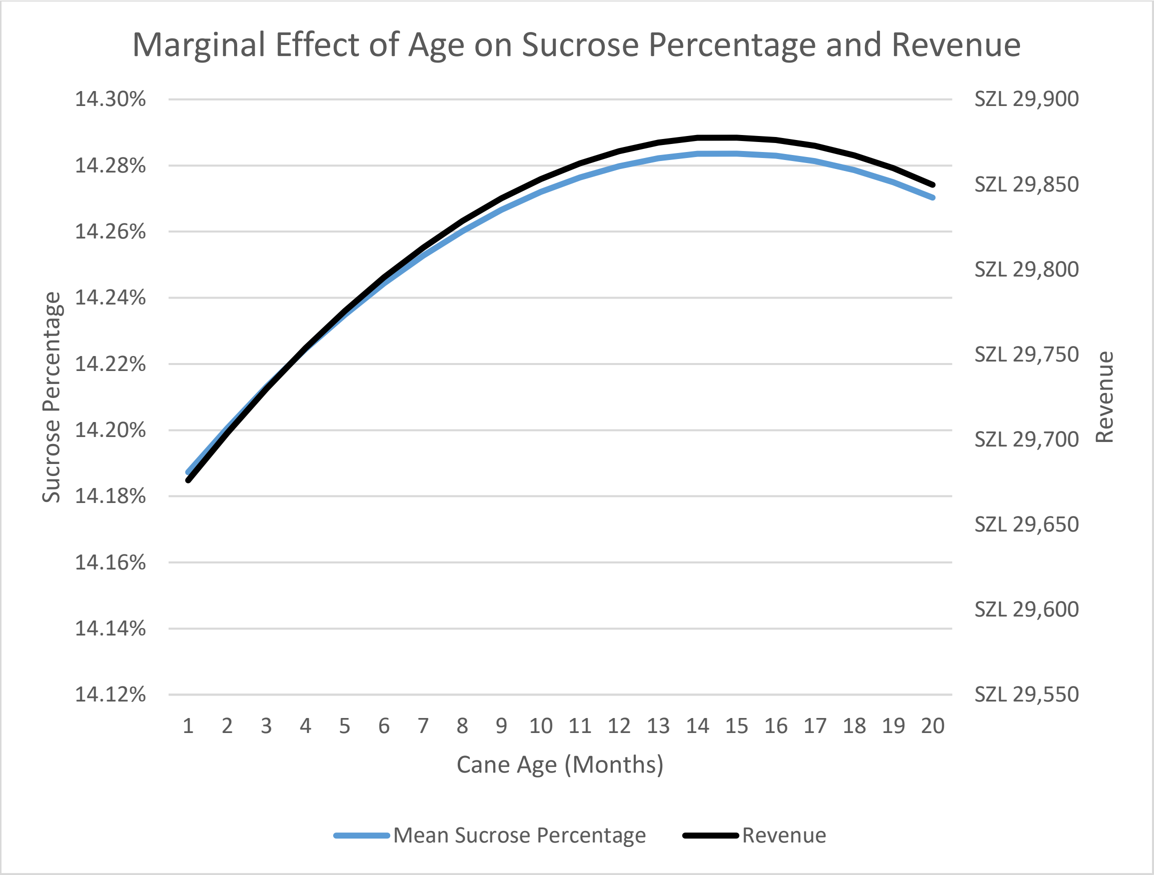

Figure 19. Marginal Effect of Age on Sucrose Percentage and Revenue (Emalangeni) [1]

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[1] As derived from coefficients from Table 15.

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Appendices

Appendix 1

Table 10b. Complete listing Farmer ID

IDM002	-26.107**	-25.949**
	(10.925)	(11.429)
IDM003	-0.324	-0.598
	(11.190)	(11.706)
IDM004	-11.835	-11.885
	(11.190)	(11.706)
IDM005	-3.800	-3.926
	(11.190)	(11.706)
IDM006	-14.707	-14.110
	(10.928)	(11.443)
IDM007	-12.696	-12.710
	(11.193)	(11.709)
IDM008	-34.875***	-34.909***
	(10.925)	(11.429)
IDM009	-7.493	-7.707
	(11.191)	(11.707)
IDM010	-16.423	-18.191
	(11.517)	(12.048)
IDM011	-34.792***	-35.348***
	(10.925)	(11.428)
IDM012	-10.958	-11.454
	(10.924)	(11.428)
IDM013	-48.671***	-49.379***
	(11.192)	(11.708)
IDM014	-10.097	-10.504
	(10.702)	(11.196)
IDM015	0.032	-0.251
	(10.703)	(11.196)
IDM016	-42.352***	-41.815***
	(11.930)	(12.501)
IDM017	-24.669**	-23.745**
	(11.518)	(12.059)
IDM019	-34.453***	-34.629***
	(10.925)	(11.428)
IDM020	-29.224**	-29.515**
	(11.515)	(12.046)
IDM021	-48.803***	-48.589***
	(11.918)	(12.467)
IDM022	-20.571*	-21.033*
	(10.925)	(11.428)

Table 10b. Complete listing Farmer ID (Cont.)

IDM023	32.402***	31.897***
	(10.926)	(11.432)
IDM024	-10.919	-11.180
	(10.703)	(11.196)
IDM025	34.678***	34.223***
	(11.190)	(11.705)
IDM026	-12.083	-12.653
	(10.925)	(11.428)
IDM027	-25.657**	-26.237**
	(10.925)	(11.428)
IDM028	-17.576	-17.952
	(10.703)	(11.197)
IDM029	-21.828**	-22.468**
	(10.924)	(11.427)
IDM030	6.557	6.507
	(10.703)	(11.199)
IDM031	-55.281***	-55.191***
	(12.438)	(13.011)
IDM032	-38.476***	-38.800***
	(10.702)	(11.196)
IDM033	-23.964**	-24.149**
	(10.702)	(11.196)
IDM034	-28.041***	-28.398**
	(10.702)	(11.196)
IDM035	-39.655***	-40.512***
	(11.192)	(11.708)
IDM036	-23.563**	-23.992**
	(11.190)	(11.705)
IDM037	-31.091***	-31.709***
	(11.515)	(12.046)
IDM038	17.445	16.639
	(11.517)	(12.048)
IDM039	-2.203	-2.951
	(10.924)	(11.428)
IDM040	-1.773	-2.626
	(11.192)	(11.707)
IDM041	-40.894***	-41.386***
	(10.702)	(11.196)
IDM042	-17.181	-17.717
	(10.702)	(11.196)

Table 10b. Complete listing Farmer ID (Cont.)

Table 10b. Complete listing Farmer ID (Cont.)

IDM043	-12.792	-13.372
	(10.702)	(11.196)
IDM044	-63.099***	-63.484***
	(12.441)	(13.015)
IDM045	-26.723**	-27.253**
	(10.702)	(11.196)
IDM046	-18.196*	-18.688*
	(10.702)	(11.196)
IDM047	-21.835*	-22.271*
	(11.192)	(11.708)
IDM048	-15.466	-16.237
	(11.192)	(11.707)
IDM049	-28.211***	-28.795***
	(10.513)	(10.998)
IDM050	14.465	12.668
	(11.193)	(11.709)
IDM051	1.989	-0.034
	(11.923)	(12.473)
IDM052	-20.691*	-21.237*
	(10.702)	(11.196)
IDM053	-16.131	-16.875
	(11.192)	(11.707)
IDM054	-3.839	-4.190
	(10.924)	(11.428)
IDM055	-6.713	-7.254
	(10.702)	(11.196)
IDM056	-6.318	-6.857
	(10.926)	(11.430)
IDM057	4.789	3.961
	(11.192)	(11.707)
IDM058	-3.568	-3.367
	(10.704)	(11.200)
IDM059	-25.571**	-25.894**
	(10.926)	(11.431)
IDM060	-8.884	-9.411
	(10.702)	(11.196)
IDM061	22.645**	21.862*
	(11.192)	(11.708)
IDM062	5.368	4.616
	(11.192)	(11.707)
IDM063	-40.829***	-41.295***
	(10.702)	(11.196)
IDM064	1.747	1.140
	(10.926)	(11.431)
IDM065	-38.601***	-39.092***
	(10.702)	(11.196)
IDM066	5.250	4.850
	(10.927)	(11.435)
IDM067	11.223	10.734
	(10.926)	(11.432)
IDM068	5.789	5.516
	(10.702)	(11.196)
IDM069	21.398*	20.805*
	(10.926)	(11.431)
IDM070	4.461	3.968
	(10.702)	(11.196)
IDM071	13.613	12.811
	(11.192)	(11.708)
IDM072	1.475	0.673
	(10.924)	(11.427)
IDM073	-24.644**	-25.468**
	(11.192)	(11.709)
IDM074	-5.834	-6.405
	(10.926)	(11.431)
IDM075	25.676**	24.869**
	(11.192)	(11.709)
IDM076	-9.747	-10.306
	(10.703)	(11.196)
IDM077	4.575	4.040
	(10.702)	(11.196)
IDM078	-1.462	-2.117
	(11.192)	(11.708)
IDM079	-2.995	-3.684
	(10.924)	(11.427)
IDM080	4.170	3.391
	(10.925)	(11.428)
IDM081	1.079	1.090
	(11.518)	(12.050)
IDM082	4.760	4.022
	(10.924)	(11.427)
IDM083	-32.644***	-34.416***
	(11.517)	(12.049)
IDM084	0.117	-0.609
	(10.924)	(11.428)
IDM085	-47.534***	-48.781***
	(11.193)	(11.709)
IDM086	15.405	14.694

Table 10b. Complete listing Farmer ID (Cont.)

	(10.924)	(11.427)
IDM087	-44.913***	-44.956***
	(14.110)	(14.764)
IDM088	9.529	8.823
	(11.192)	(11.708)
IDM089	8.728	8.024
	(10.924)	(11.427)
IDM090	3.356	3.181
	(10.703)	(11.197)
IDM091	-1.269	-1.969
	(10.924)	(11.427)
IDM092	-33.960***	-34.627***
	(10.924)	(11.427)
IDM093	6.300	5.543
	(10.924)	(11.427)
IDM094	-5.330	-5.683
	(10.702)	(11.196)
IDM095	3.542	2.807
	(10.924)	(11.427)
IDM096	-13.894	-14.557
	(10.924)	(11.427)
IDM097	10.076	9.545
	(10.702)	(11.196)
IDM098	17.722	16.897
	(11.192)	(11.708)
IDM099	-14.675	-15.387
	(10.924)	(11.428)
IDM100	9.740	9.563
	(10.703)	(11.197)
IDM101	1.738	0.918
	(11.192)	(11.708)
IDM102	-6.896	-7.440
	(10.702)	(11.196)
IDM103	8.548	7.849
	(10.924)	(11.427)
IDM104	-21.884**	-22.356**
	(10.702)	(11.196)
IDM105	-0.929	-1.454
	(10.702)	(11.196)
IDM106	-8.971	-9.713
	(10.924)	(11.427)
IDM107	-25.832**	-26.559**
	(10.924)	(11.427)
IDM108	10.690	9.920

Table 10b. Complete listing Farmer ID (Cont.)

	(10.924)	(11.427)
IDM109	-2.619	-3.179
	(10.702)	(11.196)
IDM110	4.421	3.850
	(10.702)	(11.196)
IDM111	7.132	6.808
	(10.703)	(11.196)
IDM112	-12.804	-12.497
	(10.928)	(11.440)
IDM113	12.993	12.509
	(11.190)	(11.705)
IDM114	-36.876***	-37.111***
	(10.925)	(11.428)
IDM115	-17.598	-18.344
	(10.924)	(11.427)
IDM116	-5.984	-6.655
	(10.924)	(11.427)
IDM117	-32.878***	-33.029***
	(11.516)	(12.047)
IDM118	7.378	6.751
	(10.924)	(11.427)
IDM119	24.259*	22.426*
	(12.443)	(13.018)
IDM120	-0.226	-0.613
	(10.702)	(11.196)
IDM121	-48.187***	-48.275***
	(10.926)	(11.430)
IDM122	-15.785	-14.883
	(11.196)	(11.722)
IDM123	-2.658	-3.226
	(10.924)	(11.427)
IDM124	9.351	8.624
	(10.924)	(11.427)
IDM125	-16.243	-16.887
	(11.192)	(11.707)
IDM126	-3.833	-4.013
	(10.702)	(11.196)
IDM127	1.750	1.050
	(10.924)	(11.427)
IDM128	-11.373	-12.040
	(10.924)	(11.427)
IDM129	0.519	0.548
	(11.192)	(11.709)
IDM130	-49.931***	-50.470***

Table 10b. Complete listing Farmer ID (Cont.)

	(11.194)	(11.711)
IDM131	-31.055**	-30.289**
	(12.438)	(13.012)
IDM132	-42.581***	-42.591***
	(11.192)	(11.708)
IDM133	-20.592*	-19.967
	(11.925)	(12.477)
IDM134	-31.446***	-32.274***
	(11.192)	(11.708)
IDM135	-42.235***	-42.409***
	(11.194)	(11.711)
IDM136	-47.243***	-47.847***
	(10.924)	(11.427)
IDM137	-71.253***	-71.653***
	(10.702)	(11.196)
IDM138	-46.250***	-46.387***
	(10.927)	(11.432)
IDM139	-31.719***	-32.107***
	(10.702)	(11.196)
IDM140	-30.866***	-31.055***
	(10.927)	(11.431)
IDM142	-46.743***	-47.126***
	(10.924)	(11.428)
IDM143	-59.997***	-60.770***
	(11.517)	(12.048)
IDM144	-22.853**	-23.256**
	(10.702)	(11.196)
IDM145	-28.025***	-28.400**
	(10.703)	(11.196)
IDM146	-17.699	-18.268
	(10.924)	(11.428)
IDM147	-11.984	-12.501
	(11.194)	(11.711)
IDM148	-3.446	-4.200
	(10.924)	(11.427)
IDM149	6.531	6.096
	(10.703)	(11.196)
IDM150	-9.383	-10.150
	(11.192)	(11.707)
IDM151	-17.128	-17.782
	(10.924)	(11.428)
IDM152	-20.129*	-20.793*
	(10.924)	(11.427)
IDM153	-14.419	-14.849

Table 10b. Complete listing Farmer ID (Cont.)

	(10.702)	(11.196)
IDM154	-26.976**	-27.437**
	(10.924)	(11.428)
IDM155	2.483	1.810
	(10.925)	(11.428)
IDM156	1.016	0.424
	(10.924)	(11.428)
IDM157	-4.212	-4.710
	(10.702)	(11.196)
IDM158	-11.063	-11.445
	(10.924)	(11.428)
IDM159	-20.493*	-20.966*
	(10.702)	(11.196)
IDM160	-15.686	-16.319
	(10.924)	(11.427)
IDM161	-4.229	-4.701
	(10.702)	(11.196)
IDM162	11.497	10.954
	(10.925)	(11.428)
IDM163	-44.722***	-44.846***
	(10.927)	(11.431)
IDM164	-1.162	-1.753
	(10.924)	(11.427)
IDM165	13.383	12.801
	(10.924)	(11.427)
IDM166	-15.880	-16.356
	(10.702)	(11.196)
IDM167	-33.583***	-33.998***
	(10.702)	(11.196)
IDM168	-1.877	-1.864
	(11.192)	(11.709)
IDM169	-17.581	-18.022
	(10.702)	(11.196)
IDM170	-5.540	-6.764
	(11.518)	(12.050)
IDM171	4.649	4.055
	(10.924)	(11.428)
IDM172	-27.589**	-28.867**
	(11.520)	(12.053)
IDM174	-23.020*	-22.483
	(13.138)	(13.748)
IDM175	0.877	0.329
	(10.924)	(11.427)
IDM176	-15.871	-16.289

Table 10b. Complete listing Farmer ID (Cont.)

	(10.702)	(11.196)
IDM177	-23.204**	-23.509**
	(11.190)	(11.705)
IDM178	-19.393*	-19.877*
	(10.924)	(11.428)
IDM179	-0.830	-1.140
	(10.926)	(11.430)
IDM180	-16.303	-15.317
	(11.522)	(12.058)
IDM181	-1.264	-1.728
	(10.702)	(11.196)
IDM182	-30.414***	-31.144***
	(11.517)	(12.049)
IDM183	68.954***	68.473***
	(10.926)	(11.430)
IDM184	-42.827***	-43.238***
	(10.702)	(11.196)
IDM186	-7.120	-7.595
	(10.702)	(11.196)
IDM187	-7.161	-7.685
	(10.702)	(11.196)
IDM188	-28.295***	-28.949**
	(10.924)	(11.427)
IDM189	-30.989***	-31.429***
	(10.926)	(11.430)
IDM190	-4.548	-5.162
	(11.194)	(11.711)
IDM191	23.969**	23.476**
	(10.925)	(11.428)
IDM192	-5.509	-6.037
	(10.924)	(11.428)
IDM193	-13.399	-13.714
	(10.703)	(11.197)
IDM194	-19.607*	-20.346*
	(10.924)	(11.427)
IDM195	-26.718**	-27.049**
	(11.192)	(11.708)
IDM196	-6.624	-7.371
	(10.924)	(11.427)
IDM197	-1.985	-2.728
	(10.924)	(11.427)
IDM198	-15.372	-15.946
	(10.925)	(11.428)
IDM199	-20.182*	-21.358*

Table 10b. Complete listing Farmer ID (Cont.)

	(11.517)	(12.049)
IDM200	-27.847**	-28.553**
	(11.923)	(12.474)
IDM201	-25.021**	-25.111*
	(12.444)	(13.023)
IDM202	-12.807	-12.753
	(10.704)	(11.203)
IDM203	-41.015***	-41.629***
	(10.924)	(11.427)
IDM204	-26.409**	-27.140**
	(11.192)	(11.707)
IDM205	-7.741	-8.247
	(11.517)	(12.049)
IDM206	-12.938	-12.817
	(11.521)	(12.053)
IDM207	-23.719*	-24.679*
	(12.444)	(13.020)
IDM209	-32.683***	-32.622***
	(11.200)	(11.721)
IDM210	-17.701	-17.669
	(10.928)	(11.436)
IDM211	-17.377	-18.094
	(11.923)	(12.474)
IDM212	-18.284*	-18.735*
	(10.702)	(11.196)
IDM213	-9.068	-9.688
	(10.926)	(11.430)
IDM214	-10.355	-10.367
	(10.929)	(11.435)
IDM215	-10.548	-10.450
	(10.703)	(11.199)
IDM216	9.973	9.665
	(10.926)	(11.431)
IDM217	-0.834	-1.116
	(10.927)	(11.431)
IDM218	-35.274***	-35.699***
	(11.519)	(12.051)
IDM219	-50.753***	-50.080***
	(11.199)	(11.722)
IDM220	-17.371	-19.316
	(11.923)	(12.473)
IDM221	-26.049**	-26.104**
	(11.520)	(12.066)
IDM222	-22.209**	-23.263**

Table 10b. Complete listing Farmer ID (Cont.)

	(11.194)	(11.712)
IDM223	-13.979	-15.030
	(11.194)	(11.712)
IDM224	-20.913*	-21.640*
	(10.924)	(11.427)
IDM225	-21.386**	-21.833*
	(10.702)	(11.196)
IDM226	10.622	10.064
	(10.924)	(11.427)
IDM227	-36.967***	-37.620***
	(11.515)	(12.046)
IDM228	-12.573	-13.184
	(10.924)	(11.427)
IDM229	-40.578***	-40.990***
	(10.702)	(11.196)
IDM230	-18.831*	-19.277*
	(10.702)	(11.196)
IDM231	-40.822***	-41.755***
	(11.517)	(12.049)
IDM232	-41.501***	-42.133***
	(11.191)	(11.707)
IDM233	1.971	1.433
	(10.702)	(11.196)
IDM234	-25.083**	-26.021**
	(10.926)	(11.431)
IDM235	-11.682	-12.210
	(11.192)	(11.707)
IDM236	-41.854***	-42.355***
	(10.924)	(11.427)
IDM237	-13.266	-13.613
	(10.703)	(11.197)
IDM238	-48.078***	-48.718***
	(10.924)	(11.427)
IDM239	-39.764***	-39.602***
	(10.929)	(11.435)
IDM240	-29.497***	-29.839**
	(11.190)	(11.705)
IDM241	-14.515	-14.755
	(10.927)	(11.432)
IDM242	-14.501	-15.063
	(11.191)	(11.707)
IDM243	-9.395	-9.750
	(10.702)	(11.196)
IDM244	-16.330	-16.903

Table 10b. Complete listing Farmer ID (Cont.)

	(10.924)	(11.428)
IDM245	-21.632**	-21.169*
	(10.931)	(11.439)
IDM246	-16.299	-16.690
	(10.926)	(11.431)
IDM247	-8.021	-8.705
	(11.192)	(11.708)
IDM248	-29.747***	-29.996**
	(11.194)	(11.711)
IDM249	-40.845***	-40.991***
	(10.926)	(11.431)
IDM250	-21.114*	-21.374*
	(10.926)	(11.430)
IDM251	-26.375**	-26.556**
	(11.194)	(11.711)
IDM252	-1.496	-0.829
	(12.438)	(13.011)
IDM253	-51.243***	-51.849***
	(11.194)	(11.711)
IDM254	-35.701***	-36.177***
	(11.192)	(11.708)
IDM255	-8.142	-8.061
	(11.518)	(12.050)
IDM256	-27.469**	-27.881**
	(10.702)	(11.196)
IDM257	-29.528***	-29.945***
	(10.702)	(11.196)
IDM258	-25.278**	-24.732**
	(11.202)	(11.727)
IDM259	-15.602	-16.519
	(11.192)	(11.708)
IDM260	-11.875	-13.722
	(12.443)	(13.018)
IDM261	-19.621*	-20.200*
	(10.924)	(11.427)
IDM262	-33.189***	-33.324***
	(10.927)	(11.434)
IDM263	-39.507***	-40.018***
	(11.518)	(12.052)
IDM264	-36.765***	-36.986***
	(11.192)	(11.709)
IDM265	-42.794***	-43.238***
	(10.924)	(11.428)
IDM266	-23.455**	-23.866**

Table 10b. Complete listing Farmer ID (Cont.)

	(10.704)	(11.198)
IDM267	-37.238***	-37.212***
	(10.927)	(11.433)
IDM268	-38.933***	-39.257***
	(10.926)	(11.430)
IDM269	-36.841***	-38.424***
	(11.923)	(12.473)
IDM270	-31.877***	-32.340***
	(10.702)	(11.196)
IDM271	-33.779***	-34.447***
	(10.924)	(11.427)
IDM272	-47.352***	-47.792***
	(10.926)	(11.430)
IDM273	-26.676**	-27.095**
	(10.703)	(11.196)
IDM274	-35.769***	-36.001***
	(10.925)	(11.428)
IDM275	-12.622	-13.303
	(10.924)	(11.427)
IDM276	-49.047***	-49.451***
	(10.924)	(11.428)
IDM277	-40.043***	-40.656***
	(10.924)	(11.427)
IDM278	-0.471	-1.100
	(10.924)	(11.427)
IDM279	-29.979***	-30.029***
	(10.704)	(11.199)
IDM280	-74.935***	-68.301***
	(13.186)	(14.287)
IDM281	-21.722**	-22.015**
	(10.703)	(11.196)
IDM282	-40.168***	-38.319***
	(11.523)	(12.079)
IDM283	-7.984	-8.764
	(10.924)	(11.427)
IDM284	8.134	7.341
	(10.924)	(11.427)
IDM285	-9.185	-10.382
	(11.518)	(12.049)
IDM286	-3.776	-4.419
	(10.924)	(11.427)
IDM287	-27.080**	-27.170**
	(11.192)	(11.709)
IDM288	-38.148***	-37.935***

Table 10b. Complete listing Farmer ID (Cont.)

	(11.192)	(11.709)
IDM289	-17.092	-17.623
	(10.702)	(11.196)
IDM290	-34.225***	-35.140***
	(11.517)	(12.049)
IDM291	-37.980***	-37.805***
	(11.921)	(12.471)
IDM292	-28.183***	-28.483**
	(10.926)	(11.430)
IDM293	-7.487	-8.065
	(10.702)	(11.196)
IDM294	-27.935***	-28.478**
	(10.702)	(11.196)
IDM295	-12.505	-12.966
	(10.702)	(11.196)
IDM296	-24.692**	-25.463**
	(10.924)	(11.427)
IDM297	-10.390	-11.147
	(10.924)	(11.427)
IDM298	7.365	6.822
	(10.702)	(11.196)
IDM299	-6.402	-6.890
	(10.702)	(11.196)
IDM300	-2.528	-2.800
	(10.702)	(11.196)
IDM301	-14.499	-14.927
	(10.702)	(11.196)
IDM302	9.797	9.423
	(10.702)	(11.196)
IDM303	-30.811***	-30.764**
	(11.521)	(12.057)
IDM304	-35.173***	-35.330***
	(10.928)	(11.435)
IDM305	-17.992*	-18.044
	(10.926)	(11.431)
IDM306	-24.088**	-24.764**
	(10.924)	(11.427)
IDM307	0.203	-0.366
	(10.702)	(11.196)
IDM308	12.721	11.963
	(10.924)	(11.427)
IDM309	-36.438***	-36.727***
	(10.703)	(11.197)
IDM310	-16.275	-16.614

Table 10b. Complete listing Farmer ID (Cont.)

	(10.702)	(11.196)	
IDM311	-20.225*	-20.649*	
	(10.926)	(11.430)	
IDM312	-22.855**	-22.223*	
	(11.516)	(12.048)	
IDM313	-4.534	-5.214	
	(10.924)	(11.427)	
IDM314	-17.268	-17.548	
	(11.193)	(11.709)	
IDM315	-19.686*	-19.468	
	(11.518)	(12.050)	
IDM316	-22.281**	-22.901**	
	(10.924)	(11.427)	
IDM317	-29.662***	-29.983***	
	(10.925)	(11.428)	
IDM318	9.370	8.811	
	(10.924)	(11.428)	
IDM319	1.362	0.778	
	(10.924)	(11.428)	
IDM320	-12.577	-13.708	
	(11.518)	(12.050)	
IDM321	-17.496	-18.072	
	(10.925)	(11.428)	
IDM343	-0.415	-2.082	
	(12.443)	(13.018)	
IDM348	-0.335	-1.990	
	(12.443)	(13.018)	
IDM349	11.823	10.153	
	(12.443)	(13.018)	
IDM363	-29.735**	-32.114**	
	(13.136)	(13.744)	
IDS001	12.638		
	(13.631)		
IDS002	30.131**		17.342***
	(13.631)		(6.220)
IDS005	2.997		-9.925
	(13.631)		(6.240)
IDS006	5.016		-7.741
	(13.631)		(6.239)
IDS008	-17.325		-33.876***
	(15.469)		(7.714)
IDS009	16.505		3.480
	(13.453)		(6.087)
IDS011	-1.926		-16.249***

Table 10b. Complete listing Farmer ID (Cont.)

	(13.457)	(6.156)
IDS012	19.893	6.777
	(13.454)	(6.089)
IDS013	-11.565	-23.321***
	(13.659)	(6.398)
IDS014	-6.741	-20.152***
	(13.634)	(6.240)
IDS015	4.666	-8.188
	(13.453)	(6.085)
IDS016	-14.281	-27.107***
	(13.453)	(6.085)
IDS018	-23.322	-36.052***
	(16.306)	(8.359)
IDS019	-28.632	-40.046***
	(17.610)	(9.329)
IDS021	-44.361***	-55.114***
	(14.108)	(6.622)
IDS022	5.924	-6.430
	(13.631)	(6.222)
IDS023	-21.597	-33.775***
	(13.845)	(6.421)
IDS024	-15.161	-27.773***
	(13.631)	(6.239)
IDS027	-22.654	-35.128***
	(13.845)	(6.401)
IDS028	3.992	-6.633
	(13.845)	(6.418)
IDS029	-1.457	-11.476
	(14.868)	(7.251)
IDS030	3.947	-8.896
	(13.453)	(6.085)
IDS031	-38.881***	-53.259***
	(14.115)	(6.629)
IDS032	39.062***	25.536***
	(13.848)	(6.431)
IDS035	-17.833	-30.142***
	(13.631)	(6.223)
IDS037	-21.095	-33.889***
	(16.306)	(8.347)
IDS038	14.426	-1.852
	(15.469)	(7.678)
IDS041	-7.066	-18.031***
	(14.439)	(6.884)
IDS042	8.505	-2.422

Table 10b. Complete listing Farmer ID (Cont.)

	(14.439)	(6.884)	
IDS043		-6.949	
		(8.312)	
IDU001	-6.177		
	(13.141)		
IDU002	-3.824		2.362
	(13.141)		(9.297)
IDU003	-21.141		-14.313
	(13.497)		(9.629)
IDU004	-0.806		4.934
	(13.141)		(9.305)
IDU006	-25.957*		-21.880**
	(13.965)		(10.053)
IDU007	3.203		9.469
	(13.497)		(9.635)
IDU009	-17.341		-10.916
	(13.497)		(9.632)
IDU011	1.580		7.225
	(13.142)		(9.309)
IDU013	-2.139		3.700
	(13.498)		(9.656)
IDU014	-10.019		-6.339
	(13.963)		(10.053)
IDU015	1.418		7.561
	(13.497)		(9.640)
IDU016	19.062		25.123***
	(13.141)		(9.298)
IDU017	-17.794		-11.995
	(13.142)		(9.304)
IDU018	-12.678		-6.361
	(13.497)		(9.634)
IDU019	-24.941*		-19.033**
	(13.141)		(9.300)
IDU020	-25.258*		-19.171**
	(13.141)		(9.298)
IDU021	12.765		19.021**
	(13.497)		(9.636)
IDU022	-9.129		-2.887
	(13.497)		(9.636)
IDU023	-8.197		-1.730
	(13.497)		(9.631)
IDU024	-4.757		2.974
	(13.498)		(9.640)
IDU025	-4.180		1.785

Table 10b. Complete listing Farmer ID (Cont.)

	(13.141)	(9.299)
IDU026	8.425	17.170*
	(13.957)	(10.060)
IDU027	-24.497*	-18.744**
	(13.141)	(9.305)
IDU028	-21.812*	-15.827*
	(13.141)	(9.299)
IDU029	-9.573	-3.206
	(13.497)	(9.633)
IDU030	-41.439***	-31.377***
	(15.468)	(11.437)
IDU031	-18.291	-12.044
	(13.141)	(9.309)
IDU032	8.564	16.127*
	(12.856)	(9.040)
IDU033	-24.733*	-17.463*
	(12.855)	(9.043)
IDU034	7.046	14.929*
	(12.639)	(8.860)
IDU035	15.025	23.485***
	(12.853)	(9.057)
IDU036	2.798	11.031
	(12.622)	(8.830)
IDU037	-11.972	-3.336
	(13.140)	(9.307)
IDU038	-21.947*	-13.651
	(12.852)	(9.063)
IDU039	-16.291	-8.692
	(13.957)	(10.065)
IDU040	-40.838***	-34.982***
	(13.500)	(9.638)
IDU041	-17.767	-11.171
	(13.496)	(9.646)
IDU042	-5.460	3.121
	(12.853)	(9.054)
IDU043	-45.199***	-38.633***
	(13.496)	(9.647)
IDU044	3.243	11.267
	(12.622)	(8.831)
IDU045	-31.975**	-29.566***
	(14.581)	(10.622)
IDU046	-16.467	-8.399
	(12.622)	(8.831)
IDU047	-15.295	-7.197

Table 10b. Complete listing Farmer ID (Cont.)

	(12.622)	(8.830)
IDU048	-24.527*	-16.308*
	(12.622)	(8.830)
IDU049	-23.033*	-19.428*
	(13.960)	(10.056)
IDU050	-39.193***	-29.201***
	(13.491)	(9.651)
IDU051	-10.484	-1.906
	(13.139)	(9.319)
IDU052	120.898***	125.492***
	(13.500)	(9.629)
IDU053	-28.194**	-20.540**
	(13.138)	(9.322)
IDU054	-22.766*	-14.667*
	(12.622)	(8.831)
IDU055	-25.389**	-17.060*
	(12.852)	(9.061)
IDU056	-7.393	0.542
	(12.853)	(9.050)
IDU057	-37.544***	-29.187***
	(12.852)	(9.060)
IDU059	-37.952***	-29.437***
	(12.853)	(9.055)
IDU060	-21.752*	-14.015
	(12.622)	(8.840)
IDU062	-18.742	-9.832
	(12.853)	(9.050)
IDU064	-25.158*	-16.145*
	(12.853)	(9.050)
IDU065	-14.990	-8.349
	(12.620)	(8.843)
IDU067	-11.437	-3.478
	(12.529)	(8.792)
IDU068	-21.872*	-14.540*
	(12.426)	(8.663)
IDU069	-26.928**	-19.368**
	(12.426)	(8.656)
IDU070	-5.087	-2.379
	(13.955)	(10.067)
IDU071	-5.893	-5.162
	(16.843)	(12.643)
IDU072	-27.158**	-22.738**
	(13.140)	(9.311)
IDU073	-24.529**	-16.932*

Table 10b. Complete listing Farmer ID (Cont.)

	(12.426)	(8.656)
IDU075	-51.233***	-46.784***
	(13.960)	(10.066)
IDU076	-1.760	6.002
	(12.427)	(8.654)
IDU077	-2.873	4.424
	(12.622)	(8.831)
IDU078	-2.407	5.159
	(12.430)	(8.662)
IDU079	-26.179**	-18.836**
	(12.427)	(8.664)
IDU080	-37.765***	-30.906***
	(13.138)	(9.317)
IDU081	-37.374***	-32.598***
	(13.963)	(10.073)
IDU082	-46.740***	-40.162***
	(12.620)	(8.845)
IDU084	-24.397*	-17.709*
	(12.851)	(9.083)
IDU085	-19.072	-9.800
	(13.169)	(9.417)
IDU086	-31.755**	-27.158***
	(13.957)	(10.114)
IDU087	-17.295	-13.034
	(13.495)	(9.655)
IDU088	-6.258	1.006
	(12.427)	(8.666)
IDU089	2.240	9.847
	(12.426)	(8.655)
IDU090	8.977	16.972*
	(12.618)	(8.845)
IDU091	10.466	18.024**
	(12.426)	(8.656)
IDU092	-25.114*	-19.922**
	(12.857)	(9.064)
IDU094	7.592	15.617*
	(12.849)	(9.063)
IDU095	-2.512	5.507
	(12.618)	(8.844)
IDU097	-1.764	5.037
	(12.851)	(9.058)
IDU097	-17.953	0.011
	(25.247)	(19.895)
IDU098	1.564	7.685

Table 10b. Complete listing Farmer ID (Cont.)

	(13.137)	(9.327)
IDU099	-19.068	-14.569
	(13.495)	(9.647)
IDU100	0.747	5.716
	(14.586)	(10.653)
IDU101	-12.320	-4.479
	(12.849)	(9.064)
IDU102	-11.863	-7.395
	(13.495)	(9.648)
IDU103	-4.869	-0.331
	(13.495)	(9.646)
IDU104	-5.139	-0.593
	(13.140)	(9.309)
IDU105	-8.073	-0.923
	(12.851)	(9.065)
IDU106	-25.066**	-18.950**
	(12.635)	(8.867)
IDU107	-10.314	-2.886
	(12.426)	(8.659)
IDU109	-34.071**	-30.493**
	(16.840)	(12.624)

Table 10b. Complete listing Farmer ID (Cont.)

IDU110	-23.467*	-14.226
	(13.950)	(10.095)
IDU112	-35.443***	-28.634***
	(12.621)	(8.840)
IDU114	23.293	36.299***
	(14.569)	(10.660)
IDU115	-22.733	-18.011*
	(13.952)	(10.100)
IDU116	-17.898	-7.851
	(13.487)	(9.667)
IDU117	-1.991	2.853
	(13.952)	(10.094)
IDU118	-5.129	4.738
	(13.486)	(9.670)
IDU119	9.247	19.340**
	(13.487)	(9.666)
IDU120	-19.947	-7.602
	(14.564)	(10.669)
IDU121		12.022
		(10.675)

Appendix 2

Table 11b. Complete listing Farmer ID

IDM004	-1.016**	-1.015**
	(0.462)	(0.490)
IDM005	-0.344	-0.348
	(0.462)	(0.490)
IDM006	-0.657	-0.617
	(0.451)	(0.478)
IDM007	-1.159**	-1.165**
	(0.462)	(0.490)
IDM008	0.040	0.027
	(0.451)	(0.478)
IDM009	0.290	0.279
	(0.462)	(0.490)
IDM010	0.011	-0.023
	(0.475)	(0.504)
IDM011	-0.565	-0.576
	(0.451)	(0.478)
IDM012	-0.483	-0.490
	(0.451)	(0.478)
IDM013	-0.844*	-0.848*
	(0.462)	(0.490)
IDM014	-0.799*	-0.813*
	(0.442)	(0.468)
IDM015	-0.784*	-0.791*
	(0.442)	(0.468)
IDM016	-0.711	-0.646
	(0.492)	(0.523)
IDM017	-1.373***	-1.302***
	(0.475)	(0.504)
IDM019	-0.848*	-0.853*
	(0.451)	(0.478)
IDM020	-0.694	-0.702
	(0.475)	(0.504)
IDM021	-1.487***	-1.496***
	(0.492)	(0.521)
IDM022	-0.396	-0.401
	(0.451)	(0.478)
IDM023	-0.757*	-0.756
	(0.451)	(0.478)
IDM024	0.020	0.013
	(0.442)	(0.468)
IDM025	-0.066	-0.071
	(0.462)	(0.489)
IDM026	0.239	0.227

Table 11b. Complete listing Farmer ID (Cont.)

	(0.451)	(0.478)
IDM027	0.286	0.273
	(0.451)	(0.478)
IDM028	-0.595	-0.610
	(0.442)	(0.468)
IDM029	-0.382	-0.398
	(0.451)	(0.478)
IDM030	-1.058**	-1.045**
	(0.442)	(0.468)
IDM031	-1.813***	-1.819***
	(0.513)	(0.544)
IDM032	-1.309***	-1.318***
	(0.442)	(0.468)
IDM033	-0.485	-0.484
	(0.442)	(0.468)
IDM034	-0.675	-0.687
	(0.442)	(0.468)
IDM035	-0.591	-0.608
	(0.462)	(0.490)
IDM036	-0.648	-0.653
	(0.462)	(0.489)
IDM037	-0.855*	-0.860*
	(0.475)	(0.504)
IDM038	-0.421	-0.428
	(0.475)	(0.504)
IDM039	-0.725	-0.744
	(0.451)	(0.478)
IDM040	-0.282	-0.302
	(0.462)	(0.490)
IDM041	-0.585	-0.605
	(0.442)	(0.468)
IDM042	-0.241	-0.264
	(0.442)	(0.468)
IDM043	-0.498	-0.522
	(0.442)	(0.468)
IDM044	-0.862*	-0.851
	(0.513)	(0.544)
IDM045	-0.313	-0.335
	(0.442)	(0.468)
IDM046	-1.138**	-1.159**
	(0.442)	(0.468)
IDM047	-0.888*	-0.901*
	(0.462)	(0.490)

Table 11b. Complete listing Farmer ID (Cont.)

IDM048	-1.038**	-1.054**
	(0.462)	(0.490)
IDM049	-0.110	-0.128
	(0.434)	(0.460)
IDM050	-0.134	-0.167
	(0.462)	(0.490)
IDM051	-0.910*	-0.954*
	(0.492)	(0.522)
IDM052	-0.125	-0.148
	(0.442)	(0.468)
IDM053	-0.996**	-1.010**
	(0.462)	(0.490)
IDM054	-0.999**	-0.995**
	(0.451)	(0.478)
IDM055	0.529	0.506
	(0.442)	(0.468)
IDM056	0.249	0.247
	(0.451)	(0.478)
IDM057	-0.450	-0.469
	(0.462)	(0.490)
IDM058	-0.630	-0.607
	(0.442)	(0.468)
IDM059	-1.029**	-1.050**
	(0.451)	(0.478)
IDM060	-0.990**	-1.012**
	(0.442)	(0.468)
IDM061	-0.789*	-0.806*
	(0.462)	(0.490)
IDM062	-0.925**	-0.938*
	(0.462)	(0.490)
IDM063	-1.018**	-1.035**
	(0.442)	(0.468)
IDM064	-0.074	-0.080
	(0.451)	(0.478)
IDM065	-0.427	-0.447
	(0.442)	(0.468)
IDM066	0.071	0.081
	(0.451)	(0.478)
IDM067	-0.496	-0.494
	(0.451)	(0.478)
IDM068	-0.477	-0.482
	(0.442)	(0.468)
IDM069	-0.600	-0.621
	(0.451)	(0.478)
IDM070	-0.204	-0.225

Table 11b. Complete listing Farmer ID (Cont.)

	(0.442)	(0.468)
IDM071	-0.467	-0.485
	(0.462)	(0.490)
IDM072	-0.723	-0.746
	(0.451)	(0.478)
IDM073	-0.312	-0.320
	(0.462)	(0.490)
IDM074	-0.653	-0.657
	(0.451)	(0.478)
IDM075	-0.140	-0.152
	(0.462)	(0.490)
IDM076	0.029	0.008
	(0.442)	(0.468)
IDM077	-0.532	-0.555
	(0.442)	(0.468)
IDM078	-0.878*	-0.887*
	(0.462)	(0.490)
IDM079	0.349	0.331
	(0.451)	(0.478)
IDM080	-0.402	-0.423
	(0.451)	(0.478)
IDM081	-1.075**	-1.097**
	(0.475)	(0.504)
IDM082	-0.666	-0.688
	(0.451)	(0.478)
IDM083	-0.238	-0.275
	(0.475)	(0.504)
IDM084	-0.724	-0.745
	(0.451)	(0.478)
IDM085	-0.435	-0.459
	(0.462)	(0.490)
IDM086	-0.673	-0.693
	(0.451)	(0.478)
IDM087	-2.234***	-2.270***
	(0.582)	(0.617)
IDM088	-0.951**	-0.964**
	(0.462)	(0.490)
IDM089	-0.807*	-0.826*
	(0.451)	(0.478)
IDM090	-0.518	-0.518
	(0.442)	(0.468)
IDM091	-0.758*	-0.777
	(0.451)	(0.478)
IDM092	-1.051**	-1.068**
	(0.451)	(0.478)

Table 11b. Complete listing Farmer ID (Cont.)

IDM093	-0.703	-0.725
	(0.451)	(0.478)
IDM094	-0.518	-0.531
	(0.442)	(0.468)
IDM095	-0.693	-0.715
	(0.451)	(0.478)
IDM096	-0.587	-0.603
	(0.451)	(0.478)
IDM097	-0.405	-0.427
	(0.442)	(0.468)
IDM098	-0.775^{*}	-0.795
	(0.462)	(0.490)
IDM099	-0.366	-0.387
	(0.451)	(0.478)
IDM100	-1.304^{***}	-1.305^{***}
	(0.442)	(0.468)
IDM101	-0.594	-0.613
	(0.462)	(0.490)
IDM102	-0.991^{**}	-1.014^{**}
	(0.442)	(0.468)
IDM103	-0.879^{*}	-0.897^{*}
	(0.451)	(0.478)
IDM104	-0.806^{*}	-0.825^{*}
	(0.442)	(0.468)
IDM105	-0.375	-0.396
	(0.442)	(0.468)
IDM106	-0.651	-0.673
	(0.451)	(0.478)
IDM107	-0.894^{**}	-0.914^{*}
	(0.451)	(0.478)
IDM108	-0.928^{**}	-0.951^{**}
	(0.451)	(0.478)
IDM109	-0.802^{*}	-0.825^{*}
	(0.442)	(0.468)
IDM110	-1.044^{**}	-1.067^{**}
	(0.442)	(0.468)
IDM111	-0.382	-0.392
	(0.442)	(0.468)
IDM112	-0.945^{**}	-0.901^{*}
	(0.451)	(0.478)
IDM113	-1.003^{**}	-1.009^{**}
	(0.462)	(0.489)
IDM114	-1.363^{***}	-1.371^{***}
	(0.451)	(0.478)
IDM115	-1.466^{***}	-1.486^{***}

Table 11b. Complete listing Farmer ID (Cont.)

	(0.451)	(0.478)
IDM116	-0.337	-0.355
	(0.451)	(0.478)
IDM117	-1.646^{***}	-1.653^{***}
	(0.475)	(0.504)
IDM118	-0.526	-0.540
	(0.451)	(0.478)
IDM119	-0.464	-0.508
	(0.513)	(0.544)
IDM120	-0.490	-0.502
	(0.442)	(0.468)
IDM121	-1.301^{***}	-1.304^{***}
	(0.451)	(0.478)
IDM122	-1.601^{***}	-1.558^{***}
	(0.462)	(0.490)
IDM123	-0.171	-0.182
	(0.451)	(0.478)
IDM124	-0.016	-0.036
	(0.451)	(0.478)
IDM125	-1.416^{***}	-1.422^{***}
	(0.462)	(0.490)
IDM126	-2.059^{***}	-2.057^{***}
	(0.442)	(0.468)
IDM127	-1.366^{***}	-1.383^{***}
	(0.451)	(0.478)
IDM128	-0.310	-0.325
	(0.451)	(0.478)
IDM129	-0.571	-0.576
	(0.462)	(0.490)
IDM130	-1.723^{***}	-1.721^{***}
	(0.462)	(0.490)
IDM131	-1.542^{***}	-1.525^{***}
	(0.513)	(0.544)
IDM132	-1.375^{***}	-1.372^{***}
	(0.462)	(0.490)
IDM133	-1.342^{***}	-1.339^{**}
	(0.492)	(0.522)
IDM134	-1.345^{***}	-1.356^{***}
	(0.462)	(0.490)
IDM135	-0.787^{*}	-0.802
	(0.462)	(0.490)
IDM136	-0.939^{**}	-0.949^{**}
	(0.451)	(0.478)
IDM137	-0.640	-0.652
	(0.442)	(0.468)

Table 11b. Complete listing Farmer ID (Cont.)

IDM138	-1.576***	-1.578***
	(0.451)	(0.478)
IDM139	-1.776***	-1.790***
	(0.442)	(0.468)
IDM140	-1.458***	-1.462***
	(0.451)	(0.478)
IDM142	-0.528	-0.526
	(0.451)	(0.478)
IDM143	-1.605***	-1.613***
	(0.475)	(0.504)
IDM144	-1.879***	-1.891***
	(0.442)	(0.468)
IDM145	-0.712	-0.726
	(0.442)	(0.468)
IDM146	-0.823*	-0.835*
	(0.451)	(0.478)
IDM147	-0.869*	-0.881*
	(0.462)	(0.490)
IDM148	0.084	0.062
	(0.451)	(0.478)
IDM149	-0.406	-0.424
	(0.442)	(0.468)
IDM150	-0.889*	-0.904*
	(0.462)	(0.490)
IDM151	-0.984**	-1.001**
	(0.451)	(0.478)
IDM152	-1.006**	-1.022**
	(0.451)	(0.478)
IDM153	-0.197	-0.213
	(0.442)	(0.468)
IDM154	-1.543***	-1.547***
	(0.451)	(0.478)
IDM155	-0.845*	-0.858*
	(0.451)	(0.478)
IDM156	-0.420	-0.433
	(0.451)	(0.478)
IDM157	0.150	0.130
	(0.442)	(0.468)
IDM158	-1.109**	-1.106**
	(0.451)	(0.478)
IDM159	-0.498	-0.517
	(0.442)	(0.468)
IDM160	-0.587	-0.602
	(0.451)	(0.478)
IDM161	-0.748*	-0.767

Table 11b. Complete listing Farmer ID (Cont.)

	(0.442)	(0.468)
IDM162	-0.675	-0.685
	(0.451)	(0.478)
IDM163	-1.466***	-1.478***
	(0.451)	(0.478)
IDM164	-0.607	-0.619
	(0.451)	(0.478)
IDM165	-0.664	-0.676
	(0.451)	(0.478)
IDM166	-1.143***	-1.161**
	(0.442)	(0.468)
IDM167	-0.687	-0.703
	(0.442)	(0.468)
IDM168	-0.882*	-0.891*
	(0.462)	(0.490)
IDM169	-0.825*	-0.841*
	(0.442)	(0.468)
IDM170	-1.030**	-1.049**
	(0.475)	(0.504)
IDM171	0.116	0.103
	(0.451)	(0.478)
IDM172	-0.516	-0.543
	(0.475)	(0.504)
IDM174	-1.978***	-1.984***
	(0.542)	(0.575)
IDM175	-0.612	-0.620
	(0.451)	(0.478)
IDM176	-1.083**	-1.098**
	(0.442)	(0.468)
IDM177	-1.405***	-1.402***
	(0.462)	(0.489)
IDM178	-1.659***	-1.664***
	(0.451)	(0.478)
IDM179	-0.969**	-0.991**
	(0.451)	(0.478)
IDM180	-0.788*	-0.754
	(0.476)	(0.504)
IDM181	-0.361	-0.380
	(0.442)	(0.468)
IDM182	-1.771***	-1.777***
	(0.475)	(0.504)
IDM183	-0.154	-0.168
	(0.451)	(0.478)
IDM184	-1.567***	-1.581***
	(0.442)	(0.468)

Table 11b. Complete listing Farmer ID (Cont.)

IDM186	-0.242	-0.259
	(0.442)	(0.468)
IDM187	-0.970**	-0.991**
	(0.442)	(0.468)
IDM188	0.317	0.302
	(0.451)	(0.478)
IDM189	-1.065**	-1.084**
	(0.451)	(0.478)
IDM190	-0.752	-0.770
	(0.462)	(0.490)
IDM191	0.027	0.021
	(0.451)	(0.478)
IDM192	-0.707	-0.716
	(0.451)	(0.478)
IDM193	-0.254	-0.264
	(0.442)	(0.468)
IDM194	-1.236***	-1.257***
	(0.451)	(0.478)
IDM195	-1.333***	-1.344***
	(0.462)	(0.490)
IDM196	-2.077***	-2.098***
	(0.451)	(0.478)
IDM197	-1.251***	-1.272***
	(0.451)	(0.478)
IDM198	-1.566***	-1.578***
	(0.451)	(0.478)
IDM199	-1.878***	-1.908***
	(0.475)	(0.504)
IDM200	-0.930*	-0.948*
	(0.492)	(0.522)
IDM201	-1.056**	-1.043*
	(0.514)	(0.545)
IDM202	-1.613***	-1.590***
	(0.442)	(0.468)
IDM203	-1.350***	-1.362***
	(0.451)	(0.478)
IDM204	-1.560***	-1.571***
	(0.462)	(0.490)
IDM205	-0.811*	-0.798
	(0.475)	(0.504)
IDM206	-2.077***	-2.082***
	(0.475)	(0.504)
IDM207	-1.735***	-1.747***
	(0.514)	(0.544)
IDM209	-1.361***	-1.342***

Table 11b. Complete listing Farmer ID (Cont.)

	(0.462)	(0.490)
IDM210	-1.041**	-1.018**
	(0.451)	(0.478)
IDM211	-0.999**	-1.017*
	(0.492)	(0.522)
IDM212	-1.059**	-1.076**
	(0.442)	(0.468)
IDM213	-0.600	-0.621
	(0.451)	(0.478)
IDM214	-0.748*	-0.743
	(0.451)	(0.478)
IDM215	-1.293***	-1.271***
	(0.442)	(0.468)
IDM216	-0.297	-0.299
	(0.451)	(0.478)
IDM217	-0.247	-0.248
	(0.451)	(0.478)
IDM218	-1.125**	-1.130**
	(0.475)	(0.504)
IDM219	-0.836*	-0.796
	(0.462)	(0.490)
IDM220	-1.177**	-1.218**
	(0.492)	(0.522)
IDM221	-1.253***	-1.193**
	(0.475)	(0.505)
IDM222	-1.053**	-1.067**
	(0.462)	(0.490)
IDM223	-0.786*	-0.800
	(0.462)	(0.490)
IDM224	0.254	0.234
	(0.451)	(0.478)
IDM225	-0.204	-0.221
	(0.442)	(0.468)
IDM226	0.403	0.394
	(0.451)	(0.478)
IDM227	-0.527	-0.533
	(0.475)	(0.504)
IDM228	-0.800*	-0.813*
	(0.451)	(0.478)
IDM229	-1.010**	-1.026**
	(0.442)	(0.468)
IDM230	-0.230	-0.248
	(0.442)	(0.468)
IDM231	-0.766	-0.786
	(0.475)	(0.504)

Table 11b. Complete listing Farmer ID (Cont.)

IDM232	-0.398	-0.412
	(0.462)	(0.490)
IDM233	0.012	-0.011
	(0.442)	(0.468)
IDM234	-1.150**	-1.172**
	(0.451)	(0.478)
IDM235	-0.989**	-1.009**
	(0.462)	(0.490)
IDM236	-0.220	-0.226
	(0.451)	(0.478)
IDM237	-0.006	-0.019
	(0.442)	(0.468)
IDM238	-0.468	-0.484
	(0.451)	(0.478)
IDM239	-1.020**	-1.011**
	(0.451)	(0.478)
IDM240	-0.414	-0.413
	(0.462)	(0.489)
IDM241	-0.934**	-0.943**
	(0.451)	(0.478)
IDM242	-1.661***	-1.681***
	(0.462)	(0.490)
IDM243	-1.169***	-1.179**
	(0.442)	(0.468)
IDM244	-0.242	-0.253
	(0.451)	(0.478)
IDM245	-1.401***	-1.374***
	(0.451)	(0.478)
IDM246	0.229	0.204
	(0.451)	(0.478)
IDM247	-1.757***	-1.782***
	(0.462)	(0.490)
IDM248	-2.512***	-2.543***
	(0.462)	(0.490)
IDM249	-0.381	-0.388
	(0.451)	(0.478)
IDM250	-0.292	-0.308
	(0.451)	(0.478)
IDM251	-1.029**	-1.055**
	(0.462)	(0.490)
IDM252	-0.918*	-0.923*
	(0.513)	(0.544)
IDM253	-0.877*	-0.904*
	(0.462)	(0.490)
IDM254	-0.413	-0.429

Table 11b. Complete listing Farmer ID (Cont.)

	(0.462)	(0.490)
IDM255	-0.542	-0.558
	(0.475)	(0.504)
IDM256	-1.815***	-1.830***
	(0.442)	(0.468)
IDM257	-2.003***	-2.019***
	(0.442)	(0.468)
IDM258	-2.402***	-2.365***
	(0.462)	(0.490)
IDM259	-1.385***	-1.407***
	(0.462)	(0.490)
IDM260	-0.947*	-0.992*
	(0.513)	(0.544)
IDM261	-0.411	-0.421
	(0.451)	(0.478)
IDM262	-1.739***	-1.726***
	(0.451)	(0.478)
IDM263	-2.514***	-2.515***
	(0.475)	(0.504)
IDM264	-1.777***	-1.775***
	(0.462)	(0.490)
IDM265	-0.581	-0.583
	(0.451)	(0.478)
IDM266	-0.476	-0.485
	(0.442)	(0.468)
IDM267	-1.625***	-1.621***
	(0.451)	(0.478)
IDM268	-0.590	-0.601
	(0.451)	(0.478)
IDM269	-1.017**	-1.041**
	(0.492)	(0.522)
IDM270	-1.478***	-1.494***
	(0.442)	(0.468)
IDM271	-1.318***	-1.332***
	(0.451)	(0.478)
IDM272	-0.720	-0.737
	(0.451)	(0.478)
IDM273	-0.075	-0.092
	(0.442)	(0.468)
IDM274	-0.341	-0.351
	(0.451)	(0.478)
IDM275	-0.693	-0.710
	(0.451)	(0.478)
IDM276	-0.731	-0.727
	(0.451)	(0.478)

Table 11b. Complete listing Farmer ID (Cont.)

IDM277	-0.716	-0.730
	(0.451)	(0.478)
IDM278	-0.665	-0.680
	(0.451)	(0.478)
IDM279	-0.494	-0.489
	(0.442)	(0.468)
IDM280	-1.289**	-0.797
	(0.544)	(0.597)
IDM281	-0.183	-0.192
	(0.442)	(0.468)
IDM282	-0.579	-0.473
	(0.476)	(0.505)
IDM283	-1.030**	-1.053**
	(0.451)	(0.478)
IDM284	-1.070**	-1.094**
	(0.451)	(0.478)
IDM285	-3.263***	-3.295***
	(0.475)	(0.504)
IDM286	-0.558	-0.571
	(0.451)	(0.478)
IDM287	0.189	0.176
	(0.462)	(0.490)
IDM288	-0.730	-0.740
	(0.462)	(0.490)
IDM289	-1.203***	-1.223***
	(0.442)	(0.468)
IDM290	-0.019	-0.038
	(0.475)	(0.504)
IDM291	-0.448	-0.471
	(0.492)	(0.522)
IDM292	-0.218	-0.239
	(0.451)	(0.478)
IDM293	-0.953**	-0.977**
	(0.442)	(0.468)
IDM294	-1.858***	-1.881***
	(0.442)	(0.468)
IDM295	-1.140***	-1.158**
	(0.442)	(0.468)
IDM296	-0.854*	-0.876*
	(0.451)	(0.478)
IDM297	-2.016***	-2.037***
	(0.451)	(0.478)
IDM298	-1.543***	-1.565***
	(0.442)	(0.468)
IDM299	-0.718	-0.736

Table 11b. Complete listing Farmer ID (Cont.)

	(0.442)	(0.468)
IDM300	-1.072**	-1.078**
	(0.442)	(0.468)
IDM301	-1.464***	-1.479***
	(0.442)	(0.468)
IDM302	-1.162***	-1.175**
	(0.442)	(0.468)
IDM303	-2.305***	-2.292***
	(0.475)	(0.504)
IDM304	-2.231***	-2.237***
	(0.451)	(0.478)
IDM305	-1.104**	-1.107**
	(0.451)	(0.478)
IDM306	-0.879*	-0.895*
	(0.451)	(0.478)
IDM307	-1.215***	-1.239***
	(0.442)	(0.468)
IDM308	-1.426***	-1.447***
	(0.451)	(0.478)
IDM309	-0.111	-0.120
	(0.442)	(0.468)
IDM310	-1.171***	-1.182**
	(0.442)	(0.468)
IDM311	-0.655	-0.672
	(0.451)	(0.478)
IDM312	-0.678	-0.672
	(0.475)	(0.504)
IDM313	0.072	0.054
	(0.451)	(0.478)
IDM314	-1.322***	-1.326***
	(0.462)	(0.490)
IDM315	-1.546***	-1.576***
	(0.475)	(0.504)
IDM316	-0.503	-0.516
	(0.451)	(0.478)
IDM317	-1.153**	-1.165**
	(0.451)	(0.478)
IDM318	-0.285	-0.296
	(0.451)	(0.478)
IDM319	0.058	0.045
	(0.451)	(0.478)
IDM320	-1.155**	-1.183**
	(0.475)	(0.504)
IDM321	-0.069	-0.082
	(0.451)	(0.478)

Table 11b. Complete listing Farmer ID (Cont.)

IDM343	-1.019**	-1.047*		
	(0.513)	(0.544)		
IDM348	-0.407	-0.435		
	(0.513)	(0.544)		
IDM349	-0.519	-0.545		
	(0.513)	(0.544)		
IDM363	0.007	-0.030		
	(0.542)	(0.575)		
IDS001	-0.032			
	(0.563)			
IDS002	-0.068		-0.023	
	(0.563)		(0.440)	
IDS005	-0.526		-0.395	
	(0.563)		(0.441)	
IDS006	-0.479		-0.362	
	(0.563)		(0.441)	
IDS008	-0.796		-0.529	
	(0.638)		(0.546)	
IDS009	-0.705		-0.613	
	(0.555)		(0.431)	
IDS011	-0.289		-0.097	
	(0.555)		(0.435)	
IDS012	-0.322		-0.222	
	(0.555)		(0.431)	
IDS013	-0.243		-0.153	
	(0.564)		(0.453)	
IDS014	-0.931*		-0.850*	
	(0.563)		(0.441)	
IDS015	-0.452		-0.374	
	(0.555)		(0.430)	
IDS016	-0.651		-0.575	
	(0.555)		(0.430)	
IDS018	0.073		0.374	
	(0.673)		(0.591)	
IDS019	-0.741		-0.358	
	(0.727)		(0.660)	
IDS021	-0.370		-0.253	
	(0.582)		(0.468)	
IDS022	0.525		0.534	
	(0.563)		(0.440)	
IDS023	-0.298		-0.192	
	(0.571)		(0.454)	
IDS024	-0.032		0.074	
	(0.563)		(0.441)	
IDS027	-0.224		-0.188	

Table 11b. Complete listing Farmer ID (Cont.)

	(0.571)		(0.453)	
IDS028	-0.209		-0.125	
	(0.571)		(0.454)	
IDS029	0.075		0.157	
	(0.614)		(0.513)	
IDS030	-0.367		-0.291	
	(0.555)		(0.430)	
IDS031	-0.553		-0.469	
	(0.582)		(0.469)	
IDS032	-0.679		-0.536	
	(0.571)		(0.455)	
IDS035	-1.571***		-1.566***	
	(0.563)		(0.440)	
IDS037	-0.277		0.009	
	(0.673)		(0.590)	
IDS038	0.256		0.332	
	(0.638)		(0.543)	
IDS041	-0.095		-0.138	
	(0.596)		(0.487)	
IDS042	-0.128		-0.174	
	(0.596)		(0.487)	
IDS043			-0.075	
			(0.588)	
IDU001	-0.056			
	(0.542)			
IDU002	0.116			0.173
	(0.542)			(0.305)
IDU003	-0.920*			-0.866***
	(0.557)			(0.316)
IDU004	0.101			0.110
	(0.542)			(0.305)
IDU006	-0.339			-0.315
	(0.576)			(0.330)
IDU007	-0.489			-0.464
	(0.557)			(0.316)
IDU009	0.116			0.157
	(0.557)			(0.316)
IDU011	-0.087			-0.085
	(0.542)			(0.305)
IDU013	-0.608			-0.629**
	(0.557)			(0.317)
IDU014	0.194			0.181
	(0.576)			(0.330)
IDU015	0.029			0.042
	(0.557)			(0.316)

Table 11b. Complete listing Farmer ID (Cont.)

IDU016	0.226	0.271
	(0.542)	(0.305)
IDU017	-0.090	-0.078
	(0.542)	(0.305)
IDU018	0.224	0.254
	(0.557)	(0.316)
IDU019	-0.057	-0.029
	(0.542)	(0.305)
IDU020	-0.089	-0.042
	(0.542)	(0.305)
IDU021	-0.084	-0.060
	(0.557)	(0.316)
IDU022	-0.185	-0.163
	(0.557)	(0.316)
IDU023	-0.111	-0.067
	(0.557)	(0.316)
IDU024	0.045	0.090
	(0.557)	(0.316)
IDU025	-0.325	-0.291
	(0.542)	(0.305)
IDU026	0.373	0.451
	(0.576)	(0.330)
IDU027	-0.079	-0.069
	(0.542)	(0.305)
IDU028	-0.196	-0.160
	(0.542)	(0.305)
IDU029	0.234	0.269
	(0.557)	(0.316)
IDU030	-0.590	-0.329
	(0.638)	(0.375)
IDU031	0.854	0.860***
	(0.542)	(0.305)
IDU032	-0.216	-0.141
	(0.531)	(0.296)
IDU033	0.362	0.406
	(0.531)	(0.297)
IDU034	-0.165	-0.175
	(0.522)	(0.291)
IDU035	-0.020	0.007
	(0.530)	(0.297)
IDU036	-0.129	-0.072
	(0.521)	(0.290)
IDU037	-0.230	-0.124
	(0.542)	(0.305)
IDU038	0.142	0.153

Table 11b. Complete listing Farmer ID (Cont.)

	(0.530)	(0.297)
IDU039	0.554	0.612*
	(0.576)	(0.330)
IDU040	-0.370	-0.347
	(0.557)	(0.316)
IDU041	0.370	0.363
	(0.557)	(0.316)
IDU042	-0.277	-0.237
	(0.530)	(0.297)
IDU043	-0.293	-0.303
	(0.557)	(0.316)
IDU044	-0.234	-0.198
	(0.521)	(0.290)
IDU045	-0.354	-0.510
	(0.602)	(0.348)
IDU046	-0.326	-0.284
	(0.521)	(0.290)
IDU047	0.333	0.378
	(0.521)	(0.290)
IDU048	0.613	0.669**
	(0.521)	(0.290)
IDU049	-0.428	-0.428
	(0.576)	(0.330)
IDU050	0.051	0.111
	(0.557)	(0.317)
IDU051	0.017	0.080
	(0.542)	(0.306)
IDU052	-0.094	-0.107
	(0.557)	(0.316)
IDU053	0.694	0.686**
	(0.542)	(0.306)
IDU054	0.398	0.439
	(0.521)	(0.290)
IDU055	0.136	0.150
	(0.530)	(0.297)
IDU056	-0.322	-0.252
	(0.530)	(0.297)
IDU057	0.616	0.633**
	(0.530)	(0.297)
IDU059	-0.377	-0.345
	(0.530)	(0.297)
IDU060	-0.241	-0.236
	(0.521)	(0.290)
IDU062	-0.002	0.047
	(0.530)	(0.297)

Table 11b. Complete listing Farmer ID (Cont.)

Table 11b. Complete listing Farmer ID (Cont.)

IDU064	0.381	0.438
	(0.530)	(0.297)
IDU065	0.609	0.599^{**}
	(0.521)	(0.290)
IDU067	0.302	0.299
	(0.517)	(0.288)
IDU068	-0.068	-0.057
	(0.513)	(0.284)
IDU069	0.102	0.138
	(0.513)	(0.284)
IDU070	-0.331	-0.361
	(0.576)	(0.330)
IDU071	-0.995	-1.038^{**}
	(0.695)	(0.415)
IDU072	-0.161	-0.173
	(0.542)	(0.305)
IDU073	-0.198	-0.161
	(0.513)	(0.284)
IDU075	0.606	0.639^{*}
	(0.576)	(0.330)
IDU076	-0.304	-0.249
	(0.513)	(0.284)
IDU077	0.130	0.217
	(0.521)	(0.290)
IDU078	-0.312	-0.291
	(0.513)	(0.284)
IDU079	0.290	0.298
	(0.513)	(0.284)
IDU080	-0.237	-0.195
	(0.542)	(0.306)
IDU081	0.070	0.128
	(0.576)	(0.330)
IDU082	-0.129	-0.147
	(0.521)	(0.290)
IDU084	-0.591	-0.639^{**}
	(0.530)	(0.298)
IDU085	-0.245	-0.314
	(0.543)	(0.309)
IDU086	-0.519	-0.597^{*}
	(0.576)	(0.332)
IDU087	-0.695	-0.740^{**}
	(0.557)	(0.317)
IDU088	-0.593	-0.589^{**}
	(0.513)	(0.284)
IDU089	-0.249	-0.209
	(0.513)	(0.284)
IDU090	0.299	0.332
	(0.521)	(0.290)
IDU091	-0.080	-0.045
	(0.513)	(0.284)
IDU092	-0.219	-0.242
	(0.531)	(0.297)
IDU094	-0.045	-0.014
	(0.530)	(0.297)
IDU095	-0.036	0.001
	(0.521)	(0.290)
IDU097	-0.187	-0.174
	(0.530)	(0.297)
IDU097	-0.131	0.028
	(1.042)	(0.653)
IDU098	-0.191	-0.197
	(0.542)	(0.306)
IDU099	-0.054	-0.075
	(0.557)	(0.316)
IDU100	-0.466	-0.511
	(0.602)	(0.349)
IDU101	-0.294	-0.291
	(0.530)	(0.297)
IDU102	0.043	0.019
	(0.557)	(0.316)
IDU103	0.378	0.360
	(0.557)	(0.316)
IDU104	0.111	0.118
	(0.542)	(0.305)
IDU105	0.229	0.226
	(0.530)	(0.297)
IDU106	-0.316	-0.363
	(0.521)	(0.291)
IDU107	-0.300	-0.279
	(0.513)	(0.284)
IDU109	-0.191	-0.236
	(0.695)	(0.414)
IDU110	0.295	0.342
	(0.576)	(0.331)
IDU112	-0.075	-0.070
	(0.521)	(0.290)
IDU114	-0.575	-0.487
	(0.601)	(0.350)
IDU115	-0.028	-0.088
	(0.576)	(0.331)

Table 11b. Complete listing Farmer ID (Cont.)

IDU116	-0.416	-0.332
	(0.557)	(0.317)
IDU117	0.073	0.027
	(0.576)	(0.331)
IDU118	0.202	0.268
	(0.557)	(0.317)

Table 11b. Complete listing Farmer ID (Cont.)

IDU119	-0.542	-0.453
	(0.557)	(0.317)
IDU120	0.168	0.274
	(0.601)	(0.350)
IDU121		0.074
		(0.350)