Sustainable Microforestry

An adaptive management tool for smallholder agroforestry farms in Ganze District, Kenya

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University of California, Santa Barbara

Sustainable Microforestry:

An adaptive management tool for smallholder agroforestry farms in Ganze District, Kenya

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The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Pogram. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

Naomi Tague

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Abstract

Environmental degradation is threatening the livelihoods of smallholder farmers in the semi-arid drylands of Ganze District, Kenya, on an increasingly regular basis. Many farmers in Ganze are impoverished and depend on the land for survival. However, in their efforts to supplement their incomes, farmers have intensified their land use, becoming one of the largest contributors to local deforestation and land degradation. This has led to a cycle of environmental degradation and poverty in the region. KOMAZA, a microforestry NGO, works to alleviate poverty and break this cycle by partnering with local farmers to establish a sustainable source of income through small-scale agroforestry. As a young organization, KOMAZA has limited data and limited experience to inform its management decisions. It is therefore unsure whether its agroforestry business will be financially sustainable, making it difficult to plan strategically and manage the expectations of its farmers and investors. To address this knowledge gap, we created a user-friendly adaptable tool (the GaPP Tool) that integrates a well-established growth model (3PG) with our Profit Model to allow KOMAZA to assess the economic implications of different management decisions. The GaPP Tool evaluates: (1) parameter sensitivity, (2) profit optimization, (3) the value of operational changes, and (4) long-term strategies. Our initial implementation of this tool shows that these four functions allow KOMAZA to make better informed management decisions on a site-by-site basis, given uncertainty in economic and environmental conditions.

Executive Summary

Environmental degradation is threatening the livelihoods of smallholder farmers in the semi-arid drylands of Ganze District, Kenya on an increasingly regular basis. Many farmers in Ganze are impoverished and depend on the land for survival. As they attempt to supplement their incomes, farmers are turning to the charcoal trade and have expanded and intensified their farming efforts. However, agricultural intensification and charcoal-driven deforestation has led to increased land degradation, which reduces the productivity that farmers rely on. This has created a positive feedback cycle where poverty and environmental degradation continue to accelerate each other. In order to break the cycle of poverty and environmental degradation, a source of income is needed that is both economically and environmentally sustainable.

KOMAZA, a microforestry NGO, aims to break the cycle of poverty and degradation in the region by working to alleviate poverty. KOMAZA aims to establish a sustainable source of income by partnering with impoverished farmers to establish small-scale agroforestry on their farms. KOMAZA works primarily with eucalyptus, as it is an extremely fast growing tree species that has been grown under a variety of conditions worldwide and has proven to be highly profitable (KFS, 2009). With support from KOMAZA, individual farm families plant, harvest, process, transport and sell eucalyptus trees as high-value wood products in nearby markets. KOMAZA recoups its costs at the sale of the trees and delivers all of the profits to the participating farmer, providing a large and consistent income as each new forest plot comes of age.

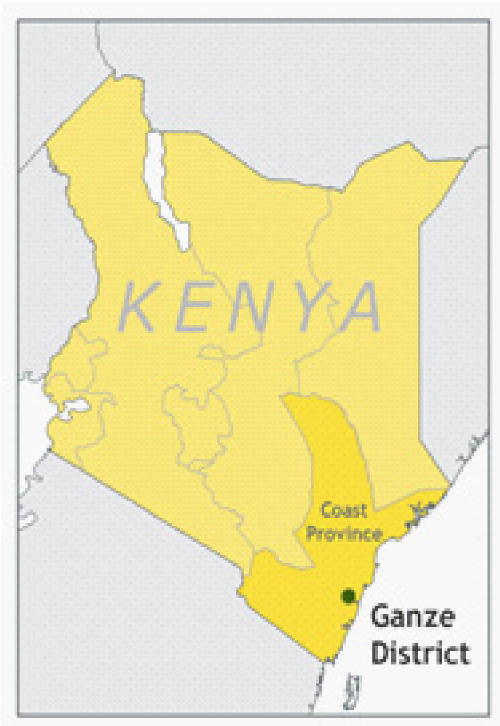


Figure 1. Map of Kenya highlighting Ganze District.

KOMAZA is a young organization, founded in 2006, and as a result, the trees that it has established have not yet reached the maturity needed for harvesting. This leaves KOMAZA reliant on donors and investors to maintain its business, with limited data and limited experience to inform its management decisions. KOMAZA is therefore unsure whether its agroforestry approach will be financially sustainable. These challenges make it difficult not only to plan strategically, but also for KOMAZA to manage the expectations of its clients and investors, which is necessary to ensure participation and community engagement in its endeavor.

Due to its limited resources, data, and experience, KOMAZA is unable to predict its profit on a site-by site basis given the uncertainty in local environmental and market conditions. As a result, it is unsure which management decisions, implemented at different spatial and temporal scales, are necessary to maximize profit. This knowledge gap makes it especially difficult to adapt its forestry strategies to the range of varying and uncertain conditions inherent to Ganze District. This leaves the organization unable to accurately predict its profitability under alternative scenarios. To maximize the success of its microforestry program, it is necessary for KOMAZA to understand the financial implications and risks of different economic and environmental conditions, and plan accordingly. As an organization with limited resources, however, its capacity to address this knowledge gap is inadequate.

85%

of households are below the poverty line in Ganze District

In order to help KOMAZA address this issue, our team has developed a flexible, easy-to-use tool and user interface for estimating forest productivity and likely profits. The purpose of this tool is to help KOMAZA develop strategic management plans by analyzing how agroforestry productivity and profitability will vary under different conditions. This will enable KOMAZA and its farmers to explore and understand the risks they face and the trade-offs present under different scenarios. To illustrate how the tool be used to aid KOMAZA's management decisions, we have provided an overview of the tool, as well as a demonstration of the major functions that the tool provides.

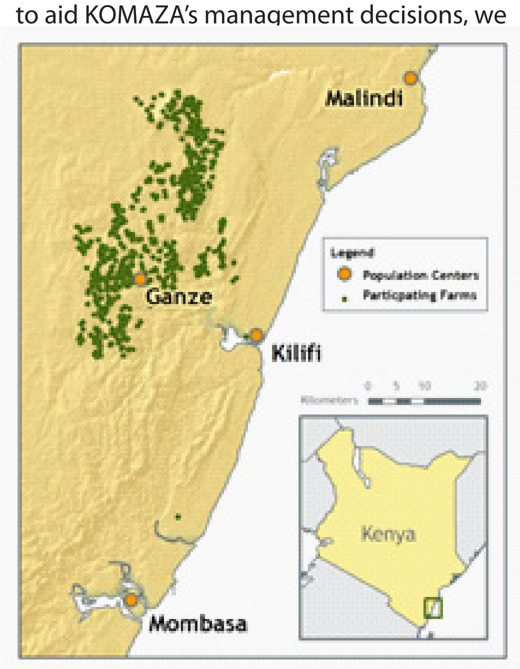


Figure 2. Locations of KOMAZA's participating farms.

The tool and user interface, which we titled the Growth and Profit Prediction (GaPP) Tool, is built from the integration of two different models. The first is a widely used biophysical model called the Physiological Principles Predicting Growth, or 3PG model. This model determines the expected amount of forest growth over time. The second model is one that we created ourselves to calculate profit under a range of scenarios. Together, these two models work together to estimate the growth and profitability of KOMAZA's operations under a variety of user-defined scenarios.

The GaPP Tool has four primary functions. Together these functions can be leveraged to create management plans capable of incorporating environmental concerns at a variety of organizational levels. The four functions build upon one another to increase the scope and precision of the resulting analyses. Specifically, the tool can be used to 1) identify sensitivity to uncertain parameters, 2) optimize current practices under a set rotation period for different scenarios, 3) model the financial value of operational changes, and 4) analyze long-term strategic management approaches.

The examples we provided demonstrate how each GaPP Tool function can be used are composed of four primary components. Within each example, we outline what is being analyzed (Objective), why KOMAZA might be interested in conducting that analysis (Significance), the results of the tool's outputs (Results), and the implications this has for KOMAZA's management practices (Management Implications). These demonstrations offer further clarity for using the GaPP Tool, as well as specific analyses that can be used to directly support KOMAZA's management needs.

A user can coordinate the strengths of the four GaPP Tool functions in two primary ways. The first is referred to as the information rich pathway, where the user begins with Tool Function 1 to provide analyses with strong, reliable data inputs. The second is referred to as the information poor pathway, which begins with Tool Function 2 and enables the user to conduct analyses under conditions of input uncertainty.

The information rich pathway begins with the sensitivity analysis provided by Tool Function 1. The sensitivity analysis is used

> "The purpose of this tool is to help KOMAZA develop strategic management plans by analyzing how agroforestry productivity and profitability will vary under different conditions."

to identify the environmental and market-based parameters that have the largest effect on profits. By beginning with this tool function, KOMAZA will be able to identify the most significant factors affecting its business, as well as determine how and where to best allocate its resources to improve information gathering. As more information is gathered, the quality and precision of input data will increase. This allows the second tool function to better optimize current practices. If the output from the second tool function is not precise enough, the user can move back and forth between the first and second tool functions until the desired precision is reached. To demonstrate how the information rich pathway utilizes the first tool function, we used the tool to model the sensitivity of tree growth to climate, soil fertility, tree species, and coppicing, as well as the sensitivity of profit to discount rate, harvest costs, and coppicing.

The information poor pathway allows the user, despite uncertainty in the input parameters, to begin with Tool Function 2. This al-

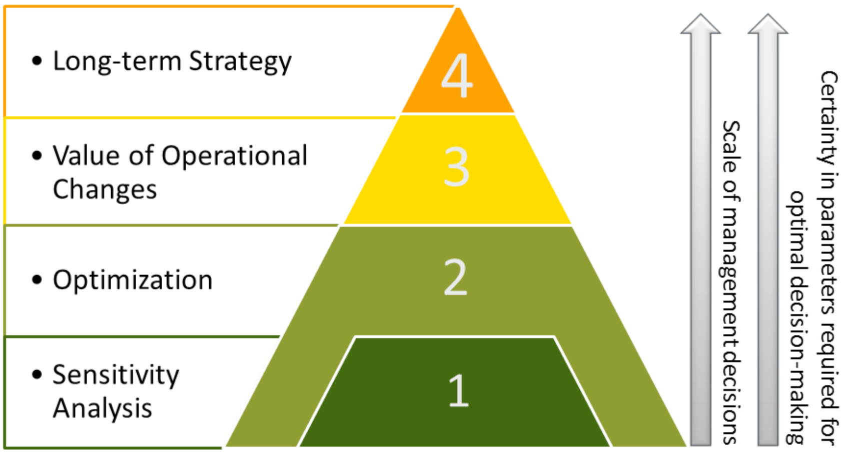


Figure 3. Tool function interactions.

lows the user to skip the time and resources needed to improve input data, and instead use the initial range in parameter uncertainty to predict the range of likely profits. Building upon the tool's ability to quantify and relate uncertain parameters, the second function can be used to optimize current practices to maximize profit under the most likely scenarios found at each individual farm. To demonstrate how the second Tool Function can be used within the information poor pathway, we determined the optimal harvest age and resulting profit and net present value of profit using a single product, using many products, and by weighting outcomes based on the probability of multiple different scenarios.

Both the information poor and information rich pathways lead to the third tool function, using this function to model the expected costs and values associated with operational changes.

Building upon the scenarios and estimations of maximum profit provided by the second and/or first tool functions, the third tool function is then used to estimate the impact of changes in operations. This allows the user to develop short term management plans and identify ways to increase revenue and reduce costs. The third tool function also aids in assessing potential trade-offs between profitability and reductions in negative environmental impacts.Building upon the first three functions of the tool, which refine the calculations for optimal harvest management to maximize profit while making operational changes, the user is then able to leverage the fourth tool function. This tool function expands the scope of analysis, allowing the user to develop long-term management strategies across large spatial and temporal scales. To permanently break the cycle of poverty and environmental degradation, KOMAZA will ultimately need to incorporate environmental sustainability into its strategic planning. The fourth tool function addresses this by helping investigate the effects of long-term trends that are likely to affect operations, such as climate change, as well as incorporate environmental sustainability in a way that minimizes reductions in profitability. The fourth tool function will also enable KOMAZA to effectively scale up its business, so that over time it can improve the financial opportunities for as many farmers as possible in an environmentally sustainable way. To demonstrate this function, we used the tool to evaluate possible effects of climate change on tree growth and profit.

Overall, the GaPP Tool takes the first steps towards fulfilling KOMAZA's need for better information about the expected tree growth and profitability of its efforts. Although KOMAZA faces the dual issues of a lack of information and a lack of resources, there are often inherent tradeoffs between efforts to address each issue. The GaPP Tool provides a way to systematically analyze the trade-offs associated with improving each of these two primary issues. Our initial implementation of this tool shows that there is not a one-size fits all solution for management decisions of different sites. The optimal harvest age, product selection, and operational decisions are likely to change under different scenarios, as was seen consistently throughout the examples. This suggests that it is important for KOMAZA to be able tailor their plans to individual farms. At the same time, while decision-making on a site-by-site basis may be beneficial, we recognize that some planning must take place at a large, region scale in order to be effective for the organization as a whole. The GaPP Tool offers analyses across spatial and temporal scales, and gives KOMAZA's planners the flexibility to choose the scale they are interested in managing.

> "This tool fills a knowledge gap and allows the organization to predict profit on multiple scales despite uncertainty in environmental and market costs."

It is up to KOMAZA's own discretion to decide whether a management analysis and decision is appropriate at a regional scale or on a site-by-site basis. This allows them to "steer the boat" through the regional and long-term management decisions while simultaneously addressing immediate management issues through short-term and site-specific planning.

It was important that this project develop the GaPP Tool so that it 1) provides better decision-making under conditions of uncertainty, 2) has a user-friendly interface, and 3) offers analyses across multiple planning horizons. As a result, the GaPP Tool is able to offer analyses that are relevant to various decision-makers throughout KOMAZA's team, from data collectors to the CEO. The fact that it was created to have a simple, two-page interface is therefore one of its critical strengths. Increased user-friendliness means that less time is needed to understand and adopt the platform, making it more likely that KOMAZA employees will be able to integrate this tool into their decision-making process. With the information the GaPP Tool produces, KOMAZA will be able to better manage the expectations of its farmers and investors, and gain better financial stability through an improved decision-making process.

In conclusion, we intend for this tool to allow KOMAZA to expand its' decision-making capacities, as well as to free up valuable time and resources for multiple employees. This tool effectively fills a knowledge gap caused by a lack of resources and a lack of experience, and now allows the organization to predict profit on multiple scales despite uncertainty in environmental and market conditions. We expect that the improved decision-making capacity will help ensure KOMAZA's financial stability and enable it to invest in other projects and goals, such as improving environmental sustainability or focusing on farmer education and awareness. We also expect that maximizing its profitability will assist KOMAZA in gaining more traction and buy-in among farmers in the region, allowing the organization to extend the positive impacts of its efforts. Ultimately, we believe that the added value to its planning capacities could help KOMAZA achieve financial sustainability and help it provide economic stability to as many farmers as possible in an environmentally sustainable way.

> " Decreased land productivity, poverty and drought conditions hinder farmers' ability to develop resiliance to economic and environmental fluctuations. "

Background

The smallholder farmers of Ganze District, Coast Province, Kenya, live in one of the driest agricultural regions in East Africa (UNDP, 2004). The farmers' livelihoods are particularly vulnerable to drought, as the region faces pressures from low and variable precipitation rates, poor soil quality, and minimal infrastructure. It has experienced regular crop failures from uneven and sporadic rains over the last decade (FAO, 1997); (Team, 2011); (USAID, 2008), causing widespread famine and the need for emergency aid intervention.

The Region

As a community that has traditionally relied on subsistence farming in a dryland region, the farming families of Ganze District have historically been impoverished, and have had limited opportunities to improve their financial stability. Furthermore, the rapid expansion of croplands in recent years due to shifts in farming policies and consumer demands has placed more intensive demands on the landscape. This expansion has stressed the land, causing decreased soil fertility and increased soil erosion throughout the region (FAO, 1997). The degradation of the land is problematic for Ganze District farmers, as decreased land productivity, combined with conditions of poverty and drought, hinders the farmers' ability to develop resilience to economic and environmental fluctuations . USAID (2008) states that environmental conditions in the region have resulted in "high rural poverty, malnutrition, disease, high mortality rates, high unemployment rates, and low life-expectancy." These factors all contribute toward reducing farmers' options for securing financial stability. As a result, during years of reduced productivity, the farmers and their families are more vulnerable to famine and have a high reliance on food aid to supplement their resources for part of the year (USAID, 2008).

In order to expand their income opportunities, many community members in Ganze have turned to the charcoal trade as an alternate source of income. This is problematic because the unregulated extraction of trees from the region has contributed to widespread deforestation in Coast Province, with forests such as the Madunguni Forest losing 86% of its forest cover between 1992-2004 (Glenday, 2008), and a total estimated loss of 90% of the region's forest cover as a whole (Githitho, 2004). Deforestation is closely associated with issues such as decreased soil quality, decreased biodiversity, carbon sequestration, and increased desertification (Fridah Mugo, 2006; S. Milledge & B. Kaale, 2003). The reduction in environmental quality caused by deforestation decreases farmers' land productivity, and results in a need for further agricultural expansion.

The charcoal trade is appealing, however,

because it has minimal up-front costs. The harvested trees are generally indigenous trees that are growing freely and are not subject to harvesting fees, allowing the harvesters to make an immediate profit. That profit, however, is minimal, with a daily average profit as low as $0.57 (Fridah Mugo, 2006), as opposed to the national average day's salary of $4.70 (CIA, 2012). The charcoal trade, combined with crop subsidies and agricultural policies that incentivize farm expansion, have contributed to widespread deforestation in the region (Kambewa et al, 2007). Most of the farmers live in areas that have historically been farmland, however, so do not always associate deforestation activities in adjacent forests with decreases in the quality of their agricultural lands, and therefore continue to unsustainably harvest trees.

The overall land degradation caused by crop expansion and deforestation ultimately limits the smallholder farmers' ability to rise out of poverty. Because many Ganze farmers are dependent on the land both for subsistence farming and as a source of income, degraded land reduces the productivity of the crops they rely on, limiting farmers' ability to save money and protect against harder times. As a result, more of their yields and income go into daily living requirements instead of investments in the future. Furthermore, the investments farmers make in the land become more costly as more money and resources are needed to produce the same amount of goods. This creates a cycle of poverty that becomes increasingly difficult to break as farmers continue to degrade the land for supplemental income in the face of increasing income instability (S. A. H. Milledge & B. K. Kaale, 2003) (Figure 4). In order to break this cycle, a source of income is needed that is both economically and environmentally sustainable.

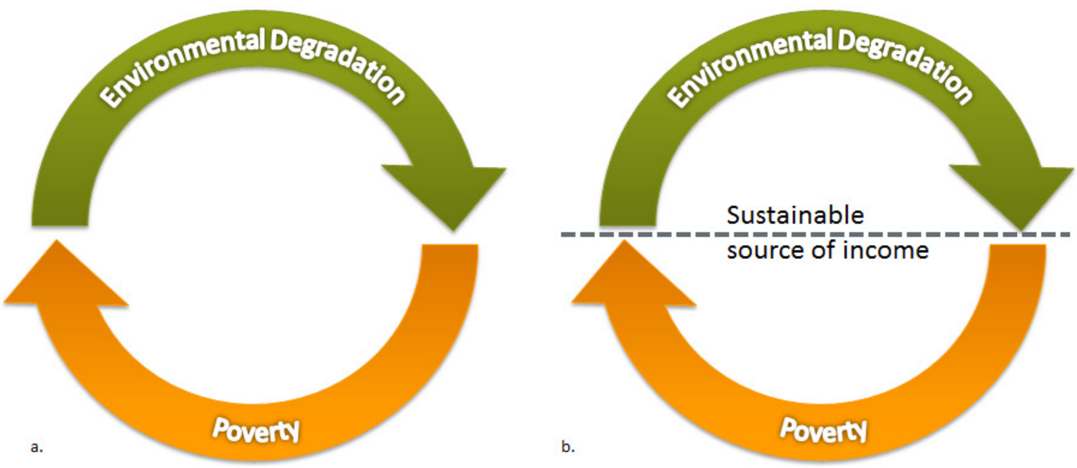


Figure 4. Poverty and Environmental Degradation Cycle. a. The cycle of poverty and environmental degradation that creates a negative feedback. b. An alternate, financially-sustainable source of income is needed to break that cycle.

The Organization

KOMAZA is a nongovernmental organization (NGO) that seeks to break this cycle of poverty by offering an alternate, financially sustainable source of income to smallholder farmers. By enabling farmers to increase and maintain their incomes, KOMAZA aims to reduce poverty while limiting the incentive to engage in environmentally destructive activities. KOMAZA recognizes the role environmental sustainability plays in alleviating poverty in the region (S. A. H. Milledge & B. K. Kaale, 2003), and therefore seeks to replace the charcoal trade and recent crop production intensification with a more profitable source of income that has less environmental impact.

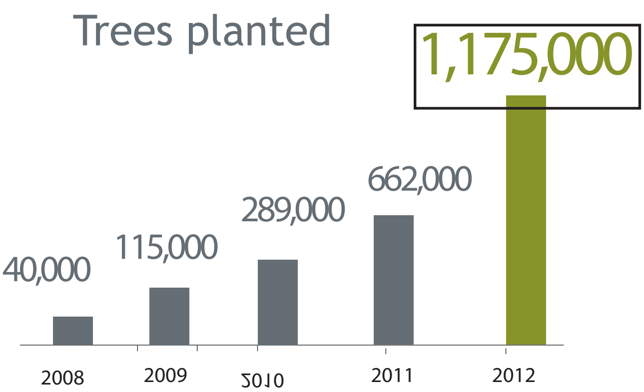
4,865

Total number of farmers participating in KOMAZA's microforestry efforts since 2008

To achieve this, KOMAZA partners with individual farm families to plant three-fourth-acre woodlots, providing farmers with high-quality seedlings and maintenance assistance on credit. With support from KOMAZA, the farmers plant, harvest, process, transport, and sell the trees as high-value wood products. KOMAZA recoups its costs at the sale of the trees and delivers all of the profits to the participating farmer, resulting in larger overall household incomes that continue over long periods of time. This also serves to decrease the farmers' dependence on increasingly expensive agricultural crops that are vulnerable to failure.

KOMAZA ultimately seeks to decrease dryland farmers' impoverishment by increasing the productivity of each farm while also reducing the deterioration of the local environment. It has been well established that both small- and large-scale forests not only reduce some of the main environmental impacts associated with crop production and other land-use degradation, they also provide a host of income sources (Fridah Mugo, 2006). Conner et al (2012) found that branching into agroforestry could "mean the difference between profit and loss in times of commodity price fluctuations" for landowners dependent on agriculture. Furthermore, agroforestry interventions in smallholder farms are found to improve ecological conditions through "reduction of soil erosion, increasing tree coverage, and maintaining soil fertility." (Nath, Inoue, & Myant, 2005).

Mission Statement: "KOMAZA is a social enterprise creating sustainable economic opportunities for farmers living in Africa's semi-arid regions. Working through village-based field staff, we partner with families and help them plant and maintain small-scale, income-generating tree farms. We call it microforestry."



About KOMAZA

Founded: 2006

Status: US-based non-profit

Location: Kilifi, Coast Province, Kenya

First tree planted: 2008

Farmers in program: 4,865

Trees planted: 1,175,000

Full-time employees: 105

> The more the farmers depend on the land to get out of poverty, the more the quality of the land is reduced, and the more their income is threatened

The Operations

Figure 5. Each successive coppice of E. grandis camaldulensis produces x% more volume of wood per year.

Image provided by Greenway Tree Care (www.greenwaytreecare.co.uk)

KOMAZA works primarily with eucalyptus for a variety of reasons. Eucalyptus is an extremely fast growing tree species that has been grown worldwide under a variety of conditions and proven to be highly profitable (KFS, 2009). Eucalyptus also coppices, meaning that when a trunk is cut during a harvest it spouts new shoots that grow to form a new genetically identical tree from the same root system. This existing root structure aids rapid addition of tree biomass, allowing more wood production over the harvest period. These coppiced sprouts can also be snipped and transplanted to form new tree seedlings. Both of these qualities greatly reduce the cost of producing eucalyptus seedlings, as they eliminate the need to plant each tree from a seed for every harvest. Also, this allows the most desirable individuals to be cloned and replicated so that entire plantations can consist of individual trees that are the most suited for their specific locale and use after harvest.

Working through village-based field staff, KOMAZA is involved in the full range of activities needed for its participating farmers to plant, grow, harvest, transport, and sell high quality wood products. KOMAZA's goal is to generate the most profit from each farm, cutting the trees once they have grown to the size necessary to be processed into the desired product. KOMAZA recoups its costs when the trees are harvested and sold, delivering all of the profit to the farmer and thereby directly alleviating poverty. The holistic process of assisted planting, growing, harvesting and transportation to markets greatly adds to the value offered by KOMAZA, providing the local farmers with a significantly higher, long-term source of income (KOMAZA, 2012a). KOMAZA enters into a non-binding contract with the farmers to formally establish their relationship, but ultimately the farmers retain control and rights over the trees and their land. The organization maintains a close relationship with the farmers before, during, and after each harvest rotation period. The farmers

The Operational Process

1

Seedlings are raised in KOMAZA's nursury

2

Distribute seedlings; help farmers clear and prepare land for planting

3

Provide annual inputs and **support** during tree's life

4

Assist farmers with **harvest** and processing

5

Transport trees to **high-value** market that partner with KOMAZA typically live on small plots of land that are roughly 10 acres in size and are generally inherited and passed down from family members through patrilineal lines. Within these plots, three to four acres are typically used for agricultural purposes. Of the remaining land, there tends to be at least one extra acre of land that is available and suitable for KOMAZA's agroforestry initiatives.

To produce the seedlings needed to establish each plot, KOMAZA has developed a eucalyptus nursery at its 'X farm' just outside the town of Ganze, where nursery staff carefully select and grow seedlings for use in the local region. This allows KOMAZA to internalize its seedling supply chain, taking advantage of economies of scale to provide lower-cost seedlings to its farmers. KOMAZA distributes these seedlings to participating farmers throughout Ganze District who then plant the seedlings to establish small plots of eucalyptus trees on their land (KOMAZA, 2012a).The farms can vary widely from one another and encompass a wide range of environmental conditions, as they range in location from the moist coastal strip to the inland, higher elevation drylands (see Figure 2). Economic considerations can also vary between farms as individual farmers may have different discount rates and certain farm plots can require different levels of input and maintenance costs, such as fertilizer or fencing.

To establish the plots, the farmers receive training concerning the best practices for preparing their land and work in conjunction with KOMAZA's support staff to clear, prepare, plant, and maintain their plots (KOMAZA, 2012a). KOMAZA's agroforestry approach is both feasible and appealing for the farmers because it is rainfed, requires minimal maintenance and upkeep, and can deliver high returns in the future. KOMAZA provides support to the farmers throughout the lives of the trees, supplying annual inputs such as fertilizer, herbicide, and water-retaining polymers, as well as seeds for short-term crops to grow while the trees mature (KOMAZA, 2012a).

Ultimately, KOMAZA harvests the plots to be sold as high quality wood products. Depending on the productivity of each individual plot, there are a variety of product options that KOMAZA can consider when planning a harvesting timeline. The Kenya Forest Service lists a wide range of uses for eucalyptus trees, ranging from pulpwood to essential oils, but for KOMAZA's business, transmission poles, timber, construction poles (referred to locally as roundwood), charcoal, and fuelwood are the most feasible product options. The demand and market prices of these products vary, but overall they produce a much higher return than traditional agricultural crops grown in the region (KFS, 2009). These products have very different uses and in the case of transmission poles and timber, the trees must be of a large diameter and length when harvested. The size of a tree increases with age, but the optimal harvest age varies depending on the productivity of the individual farm. This has a large effect on KOMAZA's management decisions, as the optimal harvest age to produce a given product can vary across farms. KOMAZA field staff help the farmers cut and collect the harvested trees, processing them as necessary to create the desired products. KOMAZA also helps transport the wood products to higher value markets that the farmers would otherwise be incapable of accessing (KOMAZA, 2012a)

Due to the coppicing of eucalyptus, the next rotation begins immediately after harvesting, with continued support from KOMAZA. Each individual tree can typically be harvested four times before the coppicing offshoots becomes less effective and the tree needs to be removed and replanted (Peralta & Swinton, 2009). KOMAZA maintains its relationships with farmers after the plots are harvested, helping the farmers devise spending strategies for their new income and ensuring that they have access to a range of investment options (KOMAZA, 2012a).

> "We plan to achieve complete financial sustainability, from individual farmers to our organization as a whole."
>
> KOMAZA's Value Proposition

Project Significance

As a young NGO, KOMAZA faces the dual challenges of having limited operational experience and limited resources. In addition, it has not yet been able to confirm whether its agroforestry business will be financially sustainable. These challenges make it difficult not only to plan strategically, but also for KOMAZA to manage the expectations of its clients and investors, which is necessary to ensure participation and community engagement in its endeavor.

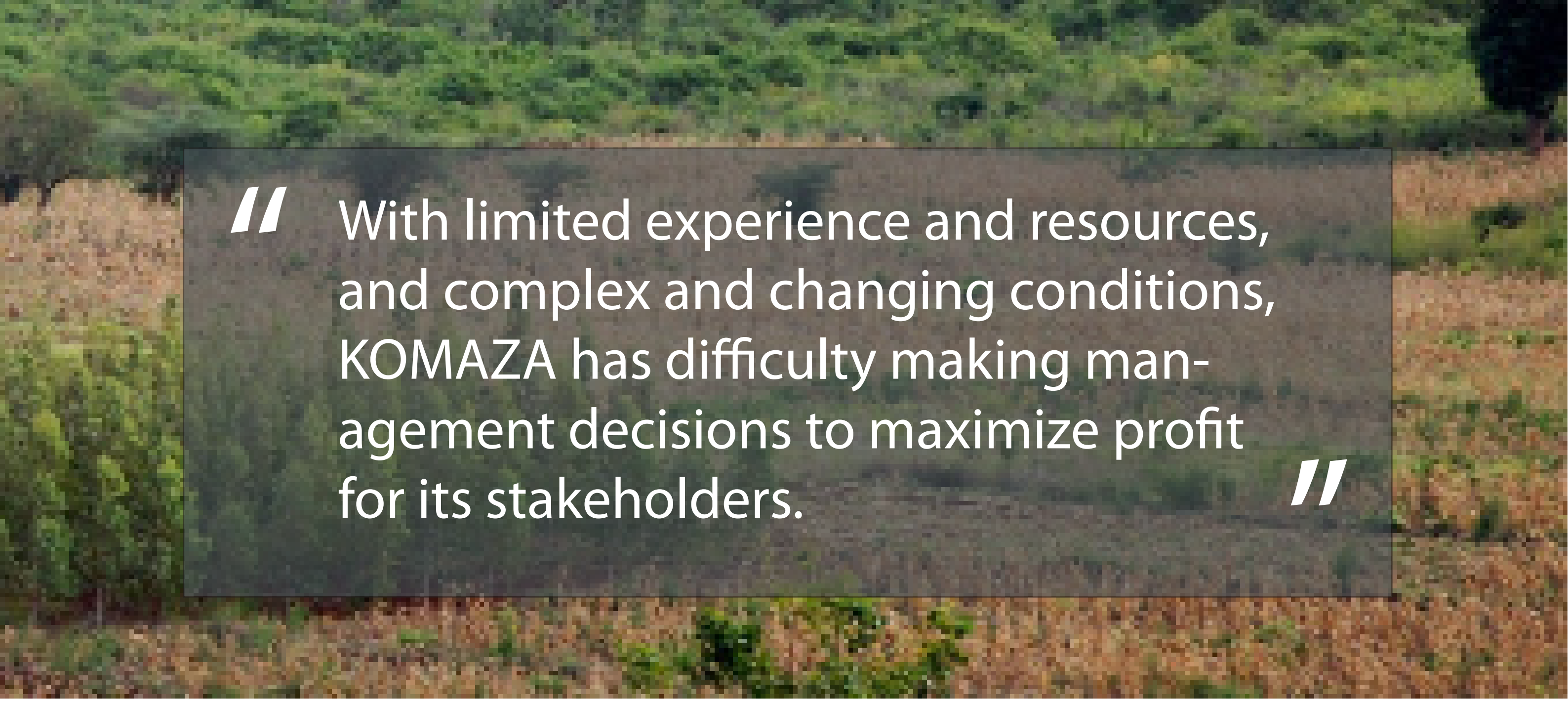
The Problem

Limited Operational Experience, Limited Resources

Until now, as a small, relatively new NGO, KOMAZA has been focusing on its primary objective of alleviating poverty by establishing its business and developing its client base throughout the region. However, KOMAZA is unable to predict its profit on a site-by site basis given uncertainty in environmental and market conditions. As a result, it is unsure which management decisions, implemented at different spatial and temporal scales, are necessary to maximize profit. This knowledge gap makes it especially difficult to adapt its agroforestry strategies to the range of varying and uncertain conditions inherent to Ganze District.

Due to the young age of KOMAZA's operations, the trees that KOMAZA has already helped establish have not yet reached the maturity needed for harvesting, given the long growing cycle inherent in agroforestry. As a result, KOMAZA is currently reliant on donors and investors to maintain its business until it can begin to recoup its operating costs through multiple harvests. Without a steady cash flow, KOMAZA has limited resources to invest in new data collection. In addition, KOMAZA has limited operational experience, leaving the organization with insufficient empirical data of the true costs and revenue it can expect from its business. Together, these resource and data limitations directly affect KOMAZA's ability to accurately estimate the profit it can expect from each farm and its operations as a whole. KOMAZA is therefore unsure whether its agroforestry business will be financially sustainable in the long run, making it difficult to convince its supporters and clients that it will be profitable.

Maintaining profitability is a top priority for KOMAZA as the more profit it can make and deliver to participating farmers, the greater impact it can have on addressing its goals of poverty alleviation and environmental concerns in the region. Therefore, KOMAZA wants to ensure that it is maximizing the success of its microforestry program. To do this, it is necessary for KOMAZA to understand the financial implications and risks of different economic and environmental conditions, and plan accordingly. As an organization with limited resources, however, its capacity to address this knowledge gap is currently inadequate.



> "With limited experience and resources, and complex and changing conditions, KOMAZA has difficulty making management decisions to maximize profit for its stakeholders."

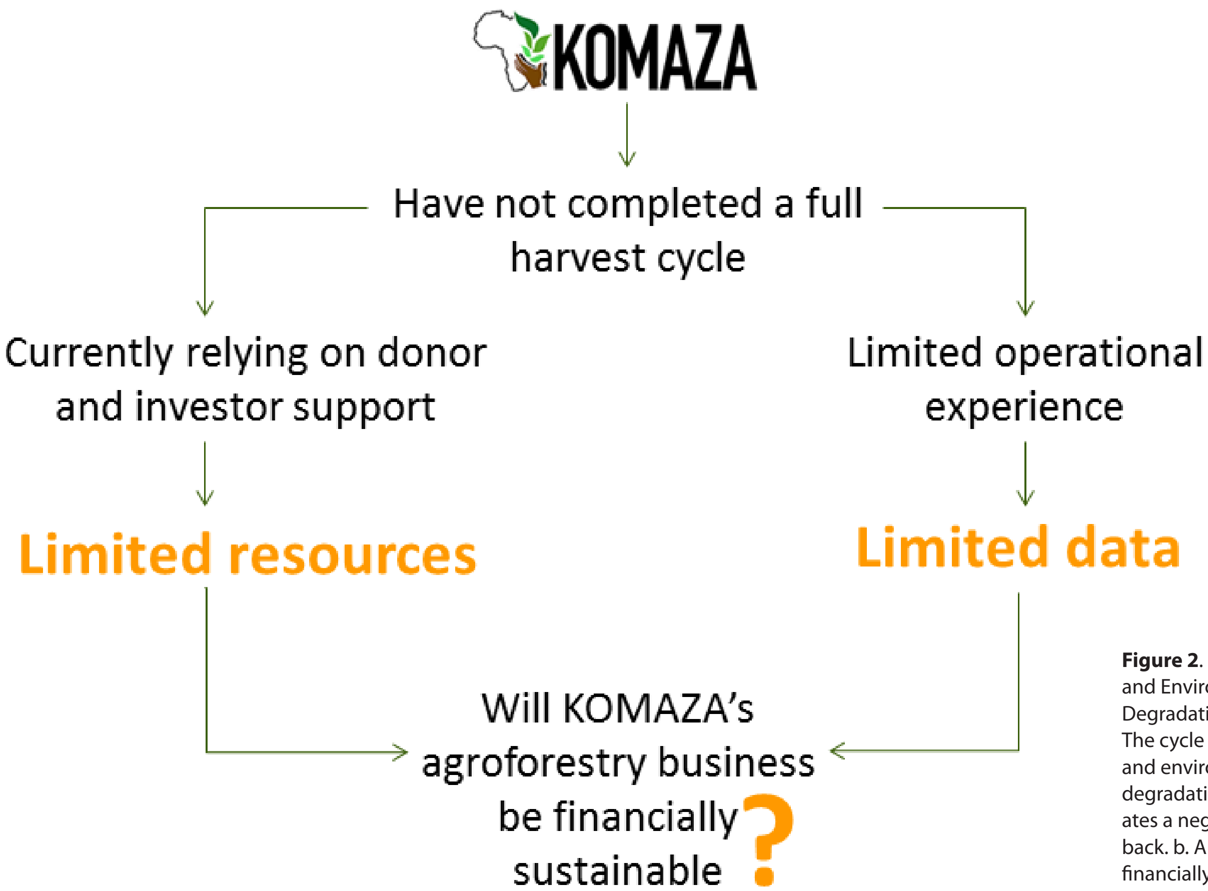


Figure 2. Poverty and Environmental Degradation Cycle. a. The cycle of poverty and environmental degradation that creates a negative feedback. b. An alternate, financially-sustainable source of income is needed to break that cycle.

Our Solution

In order to help KOMAZA address this knowledge gap, our team developed a flexible tool with a user-friendly interface that estimates forest productivity and likely profits. Together, the tool and user interface will allow KOMAZA to explore how variations and uncertainty in local environmental and market conditions will impact the profitability of its operations. In addition, to be a viable instrument capable of assisting KOMAZA with continued long-term planning, it was necessary that the tool be easy-to-use, intuitive, and adaptable.

GaPP Tool

A user-friendly, adaptive, flexiible tool that combines a biophysical model and a profit model to provide multiple planning analyses.

The purpose of this tool is to investigate how estimates of agroforestry productivity and profitability vary under different conditions, allowing KOMAZA and its farmers to understand the risks they face and the trade-offs present under different scenarios. This tool aims to help KOMAZA maximize the profitability of its agroforestry initiative through the development of strategic management plans, thereby improving the financial well-being of its stakeholders in a way that is environmentally sustainable. To that end, we engineered our tool to have the flexibility and adaptability required to conduct analyses across a range of temporal and spatial scales. This allows the tool to incorporate up-to-date information as it becomes available so that it can support better-informed decision making at various levels of KOMAZA's organization. Using this tool and the knowledge it provides, KOMAZA and its farmers will be able to more accurately develop and implement strategies that are both economically and environmentally sustainable on a farm-by-farm basis.

Objective

In order to enable KOMAZA to incorporate environmental sustainability into its operations while maintaining its profitability, this project has dual objectives:

1.) Create a flexible tool, designed to estimate forest productivity and likely profits, and

2.) Demonstrate the various functions of the tool that can be utilized by KOMAZA to aid management decisions.

Creation of the GaPP Tool

Overview

The tool and user interface, which we titled the Growth and Profit Prediction (GaPP) Tool, is built from the integration of two different models. The first, a biophysical growth model developed by Landsberg and Waring (1997), is called the Physiological Principles Predicting Growth, or 3PG model. The 3PG model determines the expected amount of forest growth over time by incorporating a variety of environmental and ecophysiological factors (see 3PG Growth Model). We specifically used a version of the model that had been tailored by Dye et al. (2004) to KOMAZA's most commonly used tree species, Eucalyptus grandis camaldulensis.

The second model is one that we created to calculate profit under a range of scenarios. To best account for uncertainty and variability in natural and market systems, a series of parameters influencing profit were selected and incorporated into the Profit Model. They include: discount rate, time horizon, stand age, rotation period, 3PG precipitation scenario, 3PG soil fertility scenario, 3PG vegetation parameter set, product choice and corresponding market price, and the costs associated with the establishment, maintenance, and harvesting of the trees (Figure 7).

The two models work together to create the GaPP Tool, a dynamic analysis tool that allows KOMAZA to estimate the impact of a number of parameters on growth and profit, ranging from soil fertility to product market prices to different species parameters (Figure 7). Furthermore, some of the parameters are separated into high, medium, and low categories to reflect the range of parameter uncertainty and variation, allowing the tool to create and analyze a large combination of environmental and market scenarios simultaneously. For example, we separated precipitation datasets into average precipitation, drier-than-normal precipitation, and wetter-than-normal precipitation. There are seven parameters included in the current version of the GaPP Tool that allow the user to consider multiple values for each parameter in any single model simulation (indicated by the filled in rectangles in Figure 7), although the tool can easily be expanded to vary additional model inputs, allowing for an infinite number of potential scenarios.

With the current inputs the tool can create over 8,500 potential scenarios given all parameter combinations. This allows the user to analyze a wide range of dynamic factors that influence the growth and profit of a microforestry plot. However, the sheer number of potential scenarios can be difficult for a user to process. We therefore found it vital to create automated graphical outputs that succinctly communicate the uncertainty bounds on estimates of profits, growth, and optimal harvest ages.

The GaPP Tool also allows analyses to be tailored to a particular site by adjusting site-specific parameters such as soil type, precipitation levels, temperature, and latitude. We are then able to select different parameters to analyze how the profitability of KOMAZA's different sites will be impacted by a variety of current and potential circumstances. In order to capture the interaction among forestry strategies and the various environmental and economic circumstances that KOMAZA operates within, we examined the growth and profitability of eucalyptus, KOMAZA's most widely grown tree, under a range of likely scenarios.

The GaPP Tool has four primary functions that can be leveraged to create management

3PG

(Physiological Principles Predicting Growth)

Source: Forestry model developed by Landsberg and Waring (1997)
Primary Function: Biophysical model of tree growth
Primary Inputs: Climate data, vegetation parameters, site parameters, stand initialization data
Primary Outputs: Diameter at Breast Height (DBH), Stand Volume

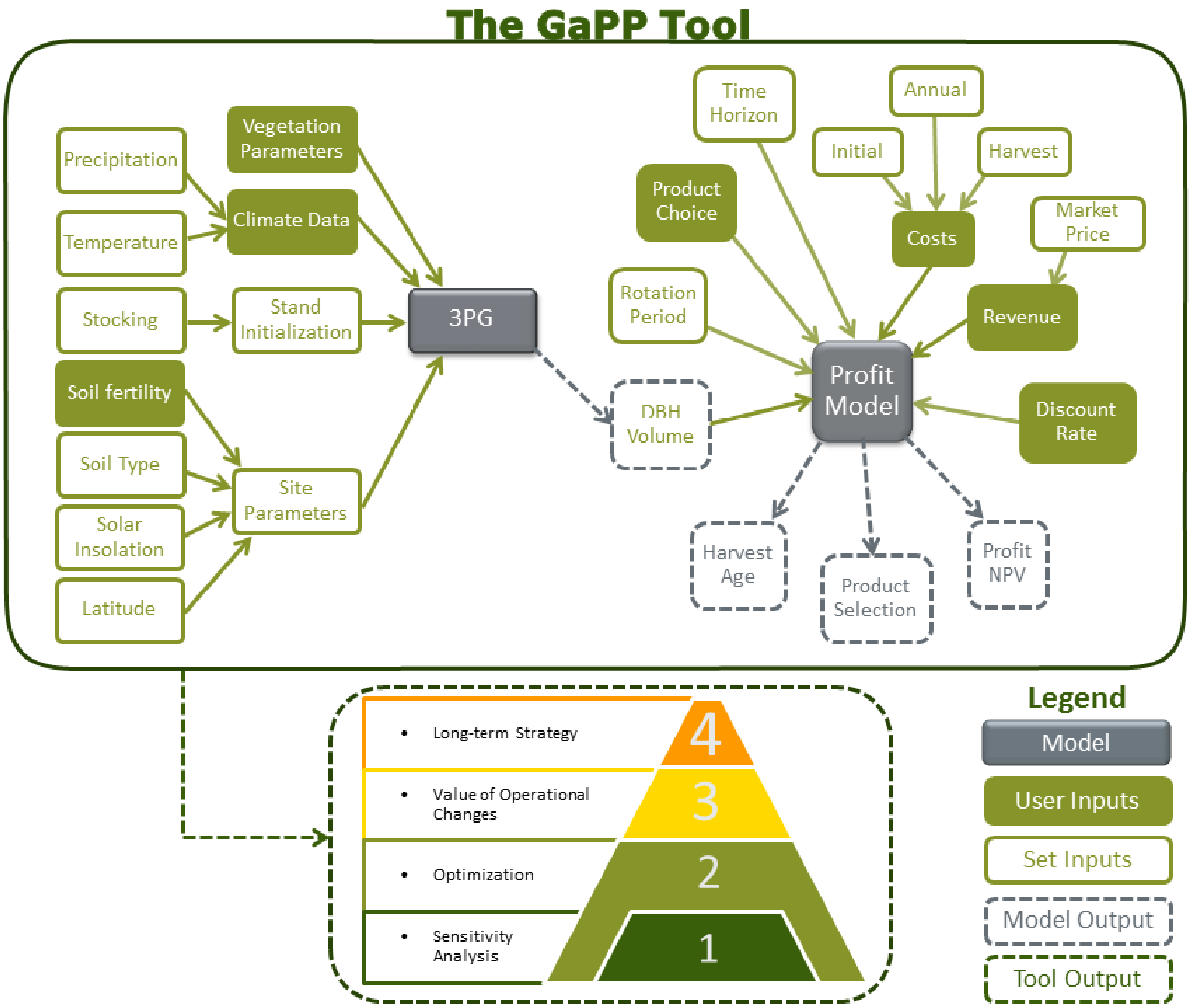


Figure 7. The GaPP Tool and Tool Functions.

plans capable of incorporating environmental concerns at a variety of organizational levels. Specifically, the tool can be used to identify sensitivity to uncertain parameters, optimize current practices under a set harvest period for different scenarios, model the financial value of operational changes, and analyze long-term strategic management approaches. The flexibility of the GaPP Tool permits the user to adapt the tool to further uses that we have not yet considered or even imagined, including incorporating further environmental impact analyses. This tool ultimately aims to assist KOMAZA in reaching its goal of formulating a long-term management plan that directly addresses local environmental concerns while still maintaining its profitability and the survival of its business.

Profit Model

Source: Created by Kenya Planit
Primary Function: Expected profit
Primary Inputs: Costs, Market Prices, Product Choices, Discount rate, 3PG Outputs
Primary Outputs: Optimal Harvest Age, Expected Net Present, Value (NPV) of profit

3PG model

In order to develop an agroforestry model able to estimate expected profit, the first step needed was a reasonably accurate prediction of the growth rate of the trees. In previous years KOMAZA has used the 3PG model, a generalized carbon allocation growth model developed by Lansberg and Waring (1997). Although the 3PG model can be used for any forest biome, KOMAZA used a variation of the 3PGpjs model that has been specifically tailored to E. grandis cameldulensis (Dye et al., 2004), as that is the species of tree KOMAZA's farmers have been planting to date.

3PG

Developed by Landsberg and Waring (1997), it stands for Physiological Principles Predicting Growth.

Although Dye and his colleagues had refined 3PG to the same species of eucalyptus, their model was tailored to South Africa, which has significantly different site and climate parameters. As a result, KOMAZA has found their farmers are experiencing growth rates that are much slower than those predicted by Dye's 3PG model. The differences between predicted and actual growth may also be a result of uncertainty and inaccuracies with parameter values used as inputs for 3PG. In order for 3PG to more accurately predict tree growth at each site, it may be necessary for KOMAZA validate the model by collecting additional data on a site-by-site basis.

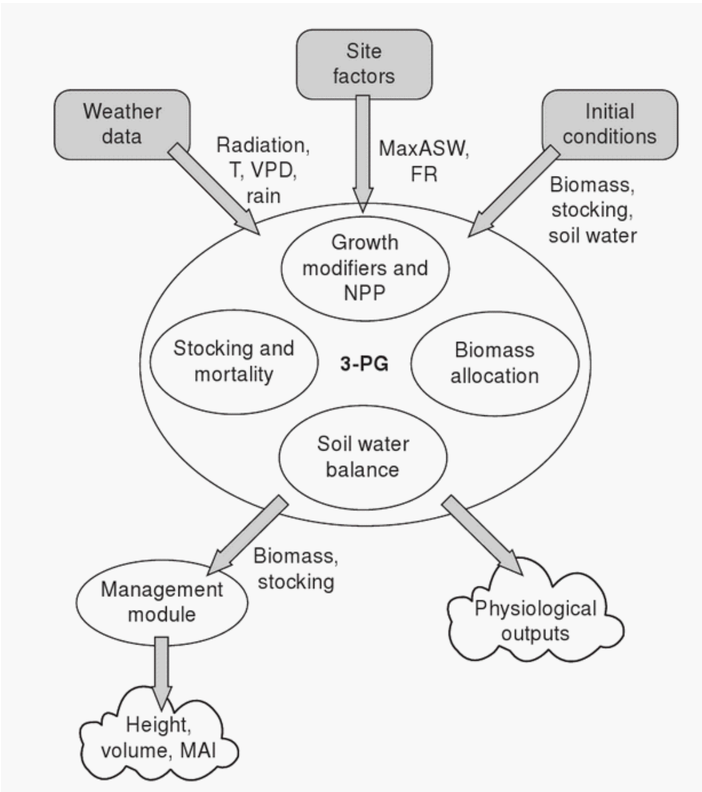


Figure 8. The inputs and outputs from the 3PG model, (Landsberg and Waring, 1997).

Despite these issues, we found the structure of 3PG to be most well-suited for the purpose of our project, and decided to refine it to be more suitable to the region. We chose to continue to use the 3PG model because we recognized that it has a number of characteristics that make it ideal for our client, making it more difficult for KOMAZA to change to a different growth model predictor. 3PG is ideal for forestry managers who have limited experience using physiological models, as it has been deliberately streamlined to require limited inputs, generate outputs that are of immediate use to foresters (such as diameter at breast height and stand volume), and it is an open source product. In addition, this model has been validated for eucalyptus plantations in studies located in Spain and Australia (J. A. Rodriguez-Suarez, 2009; P. K. Tickle, 2001; Rodríguez et al., 2006) While it was determined that 3PG accurately predicted stand volume, the research concluded that predictions of diameter at breast height (DBH) were also adequate, and could be refined with better input data. In order to tailor KOMAZA's version of 3PG to the region, we examined the site-specific parameters, which included precipitation, soil type, soil fertility, solar radiation, and vegetation parameters, and adjusted the parameters accordingly. with reliable results and it is an open source product. In order to tailor KOMAZA's version of 3PG to the region, we examined the site-specific parameters, which included precipitation, soil type, soil fertility, solar radiation, and vegetation parameters, and adjusted the parameters accordingly.

3PG Inputs

After tailoring the 3PG model to more accurately reflect the conditions in the region, we then incorporated a range of variables into 3PG that allowed us to test a variety of possible scenarios. Further details can be found in the "Supplemental Materials" report, in the section on "Developing GaPP Tool Inputs.

Latitude: The latitude for several sample sites that are located within KOMAZA's area of operation were adjusted accordingly, and ranged from -3.7° to -3.3°.

Solar Insolation: The amount of average monthly solar radiation the sites receive varies slightly throughout the year, with the region-specific values ranging from 16.24 – 22.00 MJ/m2 (OpenEI, 2013), (Boxwell, 2013). Changes in solar insolation do not vary significantly enough within the area under consideration to warrant differentiation between sites within the range of KOMAZA's current sites.

Soil Fertility: We examined a range of soil fertilities that encompass low (0.2), medium (0.5), and high fertility (0.7). These are within realistic ranges for expected fertility, and reflect fertility readings KOMAZA has observed at some of their sites.

Precipitation: Given both the impact that variable weather conditions play in tree growth and the aridity of the Ganze District, we included more precise precipitation data that was more reflective of realistically variable situations. See Supplemental Materials – Developing GaPP Tool Inputs.

Temperature: We sampled temperature using the same methods as precipitation, and then sampled precipitation and temperature together when generating our climate data for 3PG in order to capture the relationship between the two. See Supplemental Materials – Developing GaPP Tool Inputs.

Vegetation Parameters: We simulated a slightly more drought-tolerant tree species by altering several vegetation parameters of our original species E. grandis camaldulensis, to reflect increased drought resistance. We also increased the Maximum Available Soil Water (identified as Max ASW in the 3PG model) from 152 to 300, as a more drought-tolerant species characteristically has an increased ability to extract available water from the soil (Borchert, 1994).

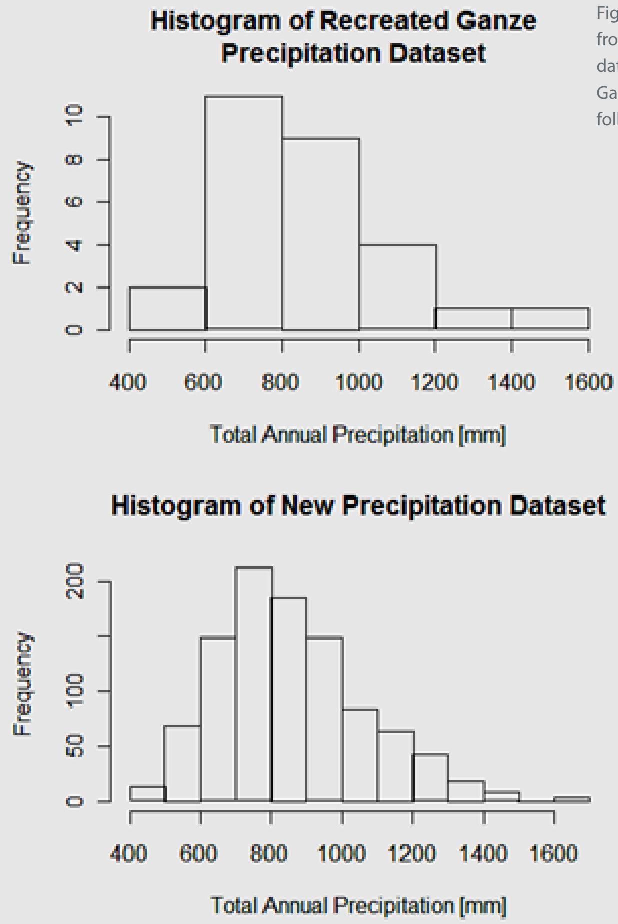


Figure 9. Rainfall patterns from the histroic Ganze dataset (top) and the new Ganze dataset (bottom) follow each other closely.

Profit Model

The Profit Model was developed to estimate the expected value of a series of harvests over a given time horizon for a single farm. In order to do that, the parameters impacting the value of each harvest were identified and initial estimates were made based on inputs from KOMAZA, Kenyan forestry reports, and industry papers.

Mathematically, the model is a series of imbedded functions that describe the relationships between each variable (Figure 10). The model examines harvest profitability in terms of the Net Present Value (NPV) of all harvests over the specified time-horizon, which is calculated as a function of the discount rate, the length of the time horizon, and the profit given by each harvest.

The profit of each harvest is defined as the expected revenue minus the expected costs of producing and selling a plot of trees as a given wood product. The function to calculate profit consists of imbedded functions that are used to calculate both revenue and costs, which vary as a function of the growth rate of the trees and the product the wood is sold as.

The growth rate, which is used to define both cost and revenue functions, is itself a function of time, the rotation period, and the 3PG model output. The 3PG model output is incorporated as yet another imbedded function, which includes climate scenarios, soil fertility, and vegetation parameters as variables.

When combined, these functions work together to form the Profit Model, providing an estimate of expected profit for a farm under the desired set of parameter values.

The Profit Model allows us to use any market price and net cost of a harvest product to determine the expected profit after a specified length of time, or even a product's optimal harvest age to maximize profit. The model is coded for and runs through the statistical software R (R 11.2), and can be adjusted to incorporate further analyses, should that be desired (see Appendix E). A number of the relationships and analyses have already been automated, but it can be further automated if KOMAZA is interested in increasing the user-friendliness and decreasing a user's learning curve.

$$NPV = \sum_{t=1}^{T} D_{time,discount\,rate} \begin{bmatrix} R_{product}\left(G_{climate,fertility,vegP,rotation\#,age}\right) \\ -C_{\mathrm{I}\;rotation\#} - C_{\mathrm{A}\;age} - C_{\mathrm{H}\;product,rotation\#} \end{bmatrix}$$

Objective: Maximize NVP by changing Harvest Age (age)

Constraint: Revenue and Cost functions must use the same product

Figure 10. Profit Model Equation. In this figure t = time in years, D = Discount factor, R = Revenue Function, G = 3PG Growth model function, C_i = Input Cost function, C_a = Annual Cost function, C_h = Harvest Cost function.

Figure 11: The three main steps of the Profit Model

Step 1:

For our demonstrations, we used 20 different tree ages at harvest, 4 rotation periods after coppicing, six possible products that the trees could be sold as, and 3 possible options of both climate and soil fertility, which result in 9 3PG scenarios.

Age		Rotation Period		Product Choice		3PG Scenario
20	x	4	x	6	x	9

=

4320 combinations

Step 2:

Calculate Profit (Revenue - Costs)

Revenue is a function of a product's market price, and the tree size at the time of harvest. The costs are divided into Input, Annual, and Harvest costs, because they occur at different stages of the agroforestry cycle, and therefore are discounted at different times

Step 3:

Maxize NVP by varying Harvest age and Product

Profit Model Output

NPV of profit over an 80-year time horizon

Produces range of climate, soil fertility, cost and revenue scenarios

Gives expected profitfor any given harvest age and products selected

> "We match the needs of the market with our partners."

KOMAZA's Value Proposition

Profit Model Inputs

Growth: This input is a measurement of volume as a function of DBH that is produced by the 3PG model, as stated earlier. Within the 3PG inputs, we varied three key factors: rainfall (high, average, and low), soil fertility (high, medium and low), and varied the vegetation options between E. grandis camaldulensis and a more drought-tolerant species.

Harvest Period: We limited each rotation period to a maximum of 20 years based on our client's understanding that it would be unlikely the farmers would be interested in waiting more than 20 years for any revenue..

Rotation Period: We limited the rotation period to four total harvest periods in order to capture the financial benefits of the coppicing effect of eucalyptus. After the fourth harvest the quality of timber produced is reduced to the point where it is no longer considered a viable product to KOMAZA (Peralta & Swinton, 2009). At this point the stump is removed and a new eucalyptus seedling is planted, restarting the rotation period. The model's planning horizon is set to 80 years to capture four rotation periods of maximum 20 year old trees.

Harvest Products: We selected six different harvest types based on KOMAZA's internal product viability analysis (see Appendix A). They are fuel wood, charcoal, roundwood, timber, untreated transmission poles, and treated transmission poles.

Discount rate: The discount rate has a built-in range to capture both KOMAZA's and the farmers' discount rates. We used a low (5%), medium (10%), and high (20%) rate where the medium reflects the rate at which KOMAZA can borrow money, based on the interest rate for one year bonds from the Central Bank of Kenya in 2008 (Peralta & Swinton, 2009). A study of eucalyptus agroforestry in Coast Province, Kenya by the Kenya Forestry Research Institute also used a discount rate of 10% (P. O. Oballa, 2010). Due to the poverty in Ganze District, the farmers have more immediate needs than KOMAZA and therefore will have a higher discount rate. To capture the likely range of this uncertainty, the discount rate used for KOMAZA was doubled. This upper bound was also used in a cost-benefit analysis between maize cultivation and eucalyptus agroforestry in Kenya, which used a range from 8% to 20% (Cheboiwo & Langat, 2010). The low discount rate of 5% was chosen because it is half the rate used for KOMAZA and is a rate that is commonly used in economic analyses in developed countries.

Initial costs: This input captures the preliminary costs associated with each tree such as procuring seedlings, seedling distribution, and woodlot preparation. Each input also has a range established from high to low in order to allow KOMAZA to test different scenarios. These costs were estimated based on information for initial costs for eucalyptus plantations calculated by the Kenya Forest Service (KFS, 2009) See Appendix A for details.

Annual costs: Unlike initial costs, the annual costs accrue each year throughout the life of the tree. These include costs such as fertilizer, pesticides, and administrative costs. Annual cost values were estimated based on cost information for eucalyptus plantations calculated by the Kenya Forest Service (KFS, 2009). Labor costs per farm were estimated by multiplying the number of KOMAZA employees by the average salaries for those employees, then dividing by the number of farms serviced by KOMAZA. See Appendix A for details.

Harvest costs: The harvest costs refer to the costs associated with each harvest product. These include harvest equipment, harvest labor, processing equipment, processing labor, and the costs associated with transporting and selling the products. A range of harvest cost values was derived from Dr. Cheboiwo, Centre Director of Lodiani Station of Kenya Forestry Research Institute. In their cost-benefit analysis, Cheboiwo and Langat approximated harvest costs for eucalyptus at 220KSh/m3 wood (Cheboiwo & Langat, 2010).

Market price: This input refers to the price a harvest product sells at on the market. Each product has a range of prices associated with it that were derived from the literature. See Appendix A for details.

Using the GaPP Tool

Overview

The GaPP Tool has a variety of forestry management planning uses which together allow KOMAZA to develop short and long term management plans that can adaptively incorporate new information as it becomes available. This will enable KOMAZA to address the environmental sustainability of it operations while maintaining or increasing the profitability of its business. The many uses of the GaPP Tool can be described in terms of its four major functions (Figure 12).

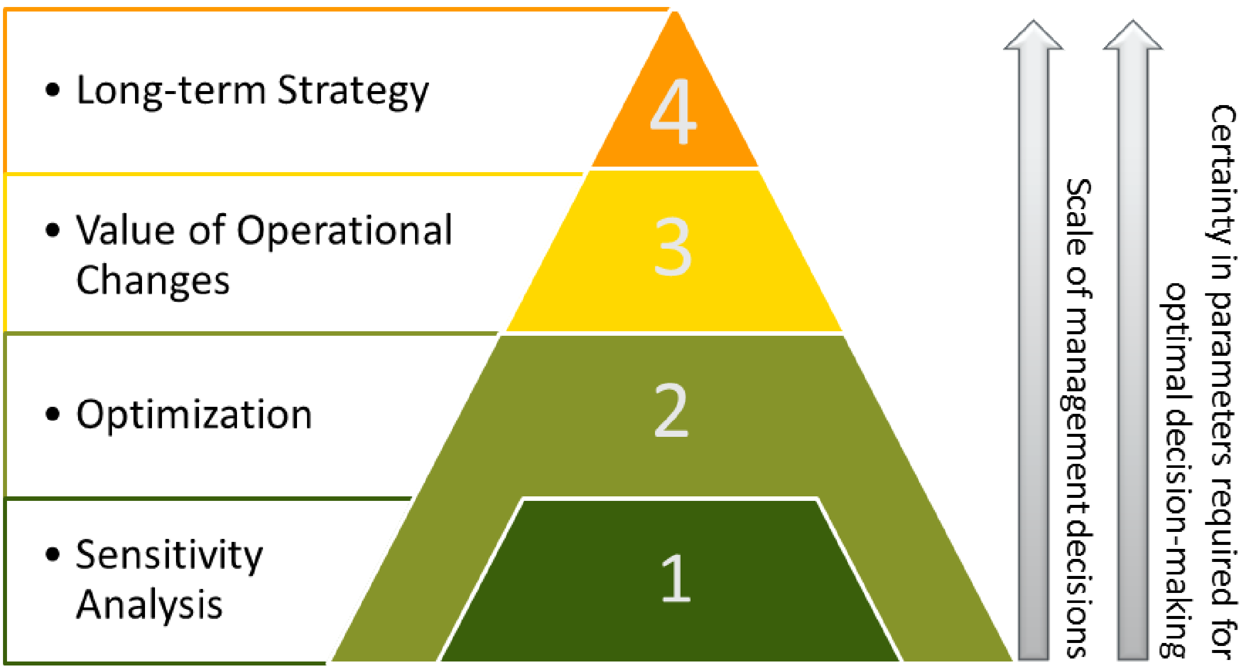
The four function of the GaPP Tool evaluate (1) parameter sensitivity, (2) profit optimization, (3) the value of operational changes, and (4) long-term strategies (Figure 12), and are described in greater detail below. The examples we provided to demonstrate how each GaPP Tool function can be used are composed of four primary components. Within each example, we outline what is being analyzed (Objective), why KOMAZA might be interested in conducting that analysis (Significance), the results of the tool's outputs (Results), and the implications this has for KOMAZA's management practices (Management Implications). These demonstrations offer further clarity for using the GaPP Tool, as well as specific analyses that can be used to directly support KOMAZA's management needs.

20

Max number of years in a harvest rotation, determined by KOMAZA's farmers' willingness to wait to harvest.

Our implementations of the Tool are by no means comprehensive, and we expect KOMAZA will continue to build on the ones we have provided. In this section we show one implementation for each tool function, but further examples can be found in the attached Supplemental Materials section. Recommendations based on specific case studies can also be found in the All Examples section.

Figure 12 Tool function interactions



Establishing Initial Parameters

Table 1 List of Scenario Defaults

Scenario Defaults	Value	Reason for Default Value
Discount rate	10%	Interest rate from the Central Bank of Kenya for 1 year bonds (2008)
Product Market Prices	Med	(Cheboiwo, 2009)
Harvest size cost	0	Only applies to certain products, so default is 0 unless product selected
Initial cost	Low	Low costs were used for demonstration purposes as higher settings often produced negative profit. (KFS, 2009)
Annual cost	Low	Low costs were used for demonstration purposes as higher settings often produced negative profit. (KFS, 2009)
Harvest cost	Low	Low costs were used for demonstration purposes as higher settings often produced negative profit. (Cheboiwo & Langat, 2010)
Climate	No default	Regularly changes throughout analyses
Tree Species	Eucalyptus	Current species KOMAZA is using
Soil Fertility	0.7	Assumes regular fertilizer applications under best possible practices

In order to have a meaningful way to analyze our model variables under uncertain conditions, we established default parameters used consistently across scenarios. Any changes to the default parameters, listed in full in Appendix A, will be defined in the results section in which they were changed. The values we chose for the default parameters are based on an average from the historical weather record, the operational practices we believe are most likely based on conversations with KOMAZA, or the most likely scenarios based on literature review. Unless it is expressly stated, we assume best possible practices for nursery and forestry management, as we know that if KOMAZA is not already currently using best possible practices, they are actively working towards achieving them. It should be understood that there is uncertainty in the parameter values used by both tools, and that these defaults are simply our best estimates.

It is valuable to note that every example described below is derived from the best available parameter values and the results of each example should be viewed only as a demonstration of the functionality of the GaPP tool and not as results that can be directly applied to KOMAZA's operations. Each example generally uses the default parameters listed in the Methods section, with any deviations from the default scenario explicitly labeled. The descriptions for Scenario Codes are seen in Table 3 (page 35).

Table 2 List of Parameter Defaults

Parameter Defaults	Value	Reason for Default Value
Max Age	20	Provided by KOMAZA
Max Year	80	Max age x Number of rotations
Hectares	1	Within reasonable range and provided clarity for results analysis
Stocking	1111	Provided by KOMAZA
Product	All	Provided by KOMAZA
Coppice	All	Changes by rotation period (Cheboiwo & Langat, 2010)
Charcoal Bag Factor	4.86	Conversion factor for standard bags/m3 wood (Kambewa, 2007)
Product DBH	Min	(Cheboiwo & Langat, 2010)

Dealing with Uncertainties

KOMAZA currently deals with uncertain inputs on a regular basis, and we are able to use the GaPP Tool to explore the implications of those uncertainties. This is valuable because many of the cost and market price values change rapidly and frequently, making it difficult for an organization like KOMAZA to predict the expected profit of its operations with precision. In order to continue exploring the impacts of uncertainties, the user can change the best guess values, which are currently based on the best available information used in our initial implementations.

Due to the inconstant nature of these inputs, it was necessary to build a range of options into the GaPP Tool to capture the inherent uncertainties in these variables and allow us to clearly see how these uncertain parameters impact the expected profits. Each parameter therefore has between two and five options for selection. This allows the user to run a variety of scenarios and develop strategies to address areas of vulnerability. The values selected from the ranges are based on either literature sources or observations from KOMAZA. In all instances the values fall within what we understand to be reasonable ranges, with the exception of variables where we are interested in testing extreme scenarios, although the extreme nature of those values are noted.

Another way that KOMAZA can calculate the expected net present value of profit if parameter values are uncertain is to assign a weight to each uncertain parameter value based on its probability of occurrence. These weights are multiplied to the corresponding NPV predicted by the GaPP tool using those parameter values, and all predicted profits are summed to get one expected value. We assigned probabilities using our best estimates from the literature, and we expect that KOMAZA will continue to refine those estimates as they gain further experience.

We have included a blank worksheet within the model that allows KOMAZA to input separate values for each parameter. The default parameters can be changed in the advent of updated data, as in the 3PG model, but the blank worksheet also allows the organization to run a variety of irregular "what-if" scenarios that test more extreme circumstances. It is important to recognize that there is inherent uncertainty in the 3PG parameters. The 3PG model uses set values for the vegetation parameters that describe a given tree, but there is plasticity within these parameters that is dependent on seed quality, nursery practices, mortality rates, and other factors that can influence how a seed grows into a seedling and beyond.

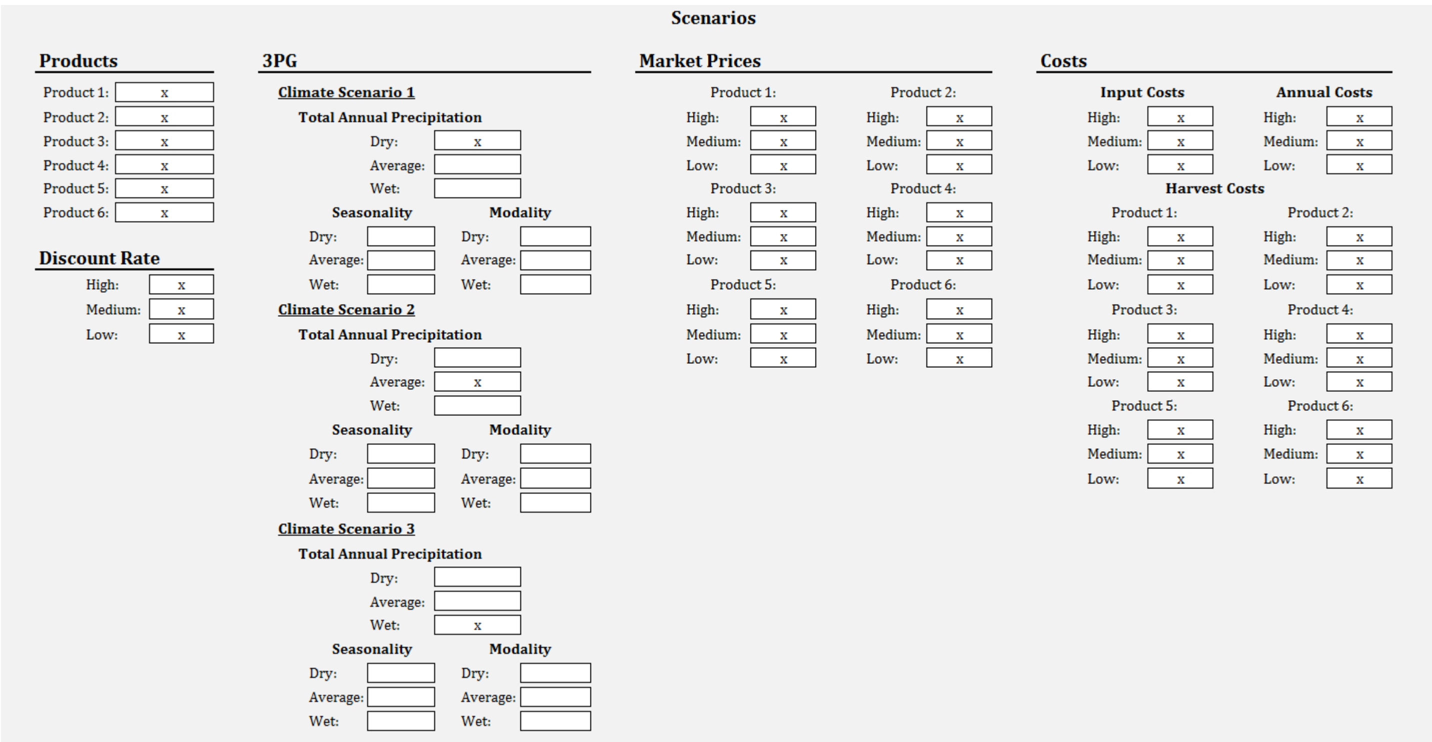


Figure 13. The GaPP Tool's user-friendly interface.

Information Rich Pathway

The information rich pathway begins with the sensitivity analysis provided by Tool Function 1. In situations where the user has more time and resources available to conduct more detailed analyses, we recommend utilizing this pathway. Instead of beginning with harvest optimization in Tool Function 2, the user can employ the sensitivity analysis in Tool Function 1 to have a more comprehensive understanding of the impacts that parameters will have on the management decision they are considering. By beginning with this tool function, KOMAZA will be able to identify the most significant factors affecting its business, as well as determine how and where to best allocate its resources to improve information gathering.

As more information is gathered, the quality and precision of input data will increase. This allows the second tool function to better optimize current practices. If the output from the second tool function is not precise enough, the user can move back and forth between the first and second tool functions until the desired precision is reached. To demonstrate how the information rich pathway utilizes the first tool function, we used the tool to model the sensitivity of tree growth to climate, soil fertility, tree species, and coppicing, as well as the sensitivity of profit to discount rate, harvest costs, and coppicing.

Information Poor Pathway

The GaPP Tool is equipped to provide analyses with both strong, reliable data inputs, and under conditions of input uncertainty. Although the latter is not ideal, this is a reality for our client at this time. The information poor pathway is one where, despite uncertainty in the input parameters, the user begins with optimization in Tool Function 2.

The second tool function has the ability to optimize current management practices to maximize profit or net present value. Building upon the tool's ability to quantify and relate uncertain parameters, the second function of the tool can be used to optimize current practices under the likely scenarios found at each individual farm. This function also allows the user to predict the range of profits given a range in parameter uncertainty, as well as to predict the expected profit given different probabilities of occurrence for each parameter value. To demonstrate how the second Tool Function can be used, we have determined the optimal harvest age and resulting profit and net present value of profit using a single product, using many products, and by weighting outcomes based on the probability of multiple different scenarios.

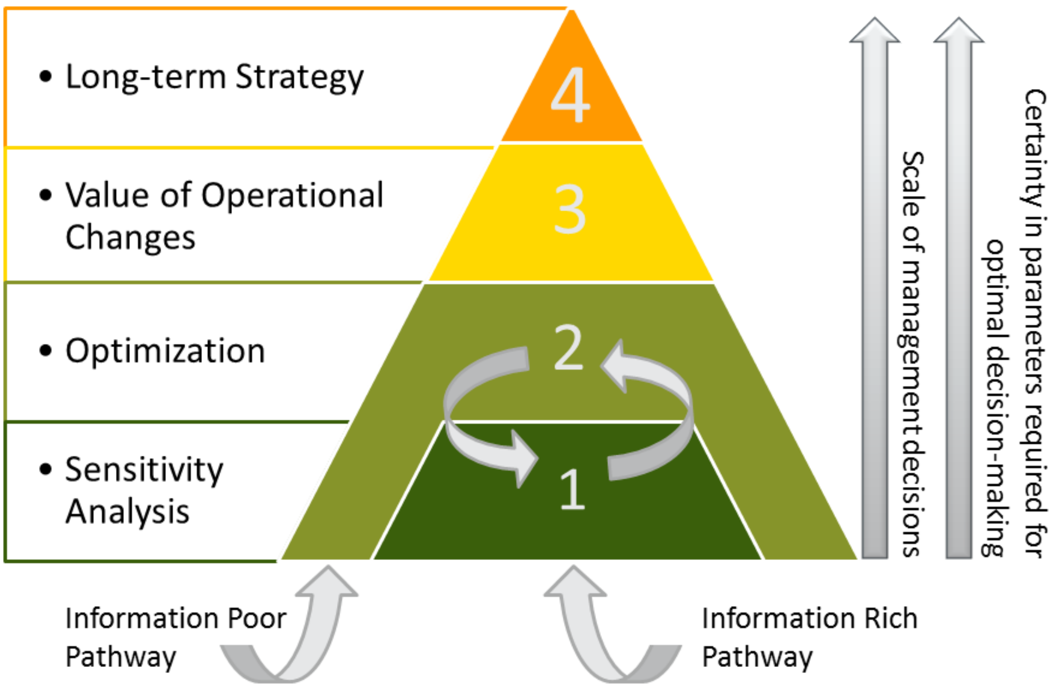


Figure 14. Even with poor information, analyses can be done by starting with Tool Function 2. Starting with Tool Function 1, however, will provide more information on how sensitivie a parameter is. The user can move between Tool Function 1 and 2 to keep refining the accuracy of their results.

Value of Operational Changes

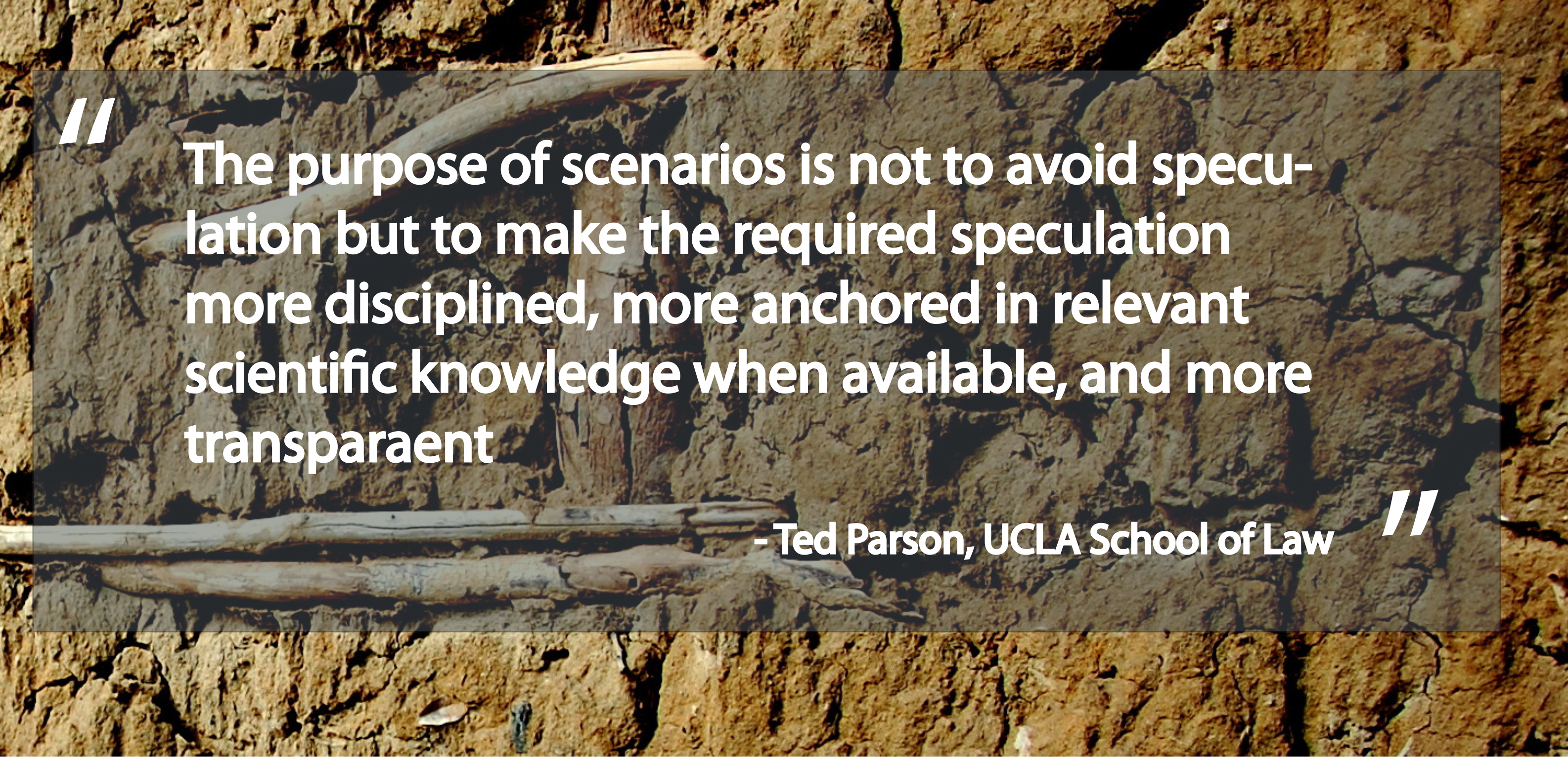
KOMAZA's lack of long-term data and operational experience limit its ability to assess the value of operational changes. Having the ability to assess the impacts of operational changes is critical because it can allow an organization to weigh the tradeoffs associated with different management practices, enabling KOMAZA to maximize the impacts of its goals, such as financial returns or environmental benefits. The third tool function has the ability to model the expected costs and values associated with operational changes. This function builds on the capabilities of the first and second tool functions that have maximized profits under the current operations by estimating the impact of changes in the operations.

The capabilities of the third tool funtion allow the organization to develop short term management plans and identify ways to increase revenue and reduce costs. It will also aid in assessing potential trade-offs between profitability and reductions in negative environmental impacts. To demonstrate this function, we have modeled the value of transporting products to a more profitable market, the value of increasing or decreasing fertilizer use at different stages of tree growth, and also conducted a comparative analysis of maximum profit for treated poles versus untreated poles.

Long Term Strategy

KOMAZA can then leverage the fourth tool function by building upon the first three functions of the tool, which refine the calculations for optimal harvest management to maximize profit while making operational changes. This tool function expands the scope of analysis to large spatial and temporal scales that are likely to affect KOMZAZA's entire operations. Expanding the scope of analysis to large spatial and temporal scales is an important component to a comprehensive management plan. This will allow KOMAZA to address issues that are likely to affect its' entire operation, such as climate change, long-term environmental sustainability, or strategic expansion. Examining long term impacts will enable KOMAZA to effectively scale up its business, so that over time it can improve the financial opportunities for as many farmers as possible in an environmentally sustainable way.

To permanently break the cycle of poverty and environmental degradation, KOMAZA will ultimately need to incorporate environmental sustainability into its strategic planning. The fourth tool function can investigate the effects of long-term trends that are likely to affect operations, such as climate change, as well as incorporate environmental sustainability in a way that minimizes reductions in profitability. This will enable KOMAZA to effectively scale up its business, so that over time it can improve the financial opportunities for as many farmers as possible in an environmentally sustainable way. To demonstrate this function, we have used the tool to evaluate possible effects of climate change on tree growth and profit.



> "The purpose of scenarios is not to avoid specu-lation but to make the required speculation more disciplined, more anchored in relevant scientific knowledge when available, and more transparaent"
>
> - Ted Parson, UCLA School of Law

Table 3. Description of Scenario codes found in the GaPP Tool Examples

Code		Scenario	
	Profit Model Inputs		
LC	Low cost	LCLR	Low cost, low revenue
MC	Medium cost	LCMR	Low cost, medium revenue
HC	High cost	LCHR	Low cost, high revenue
LR	Low revenue	MCLR	Medium cost, low revenue
MR	Medium revenue	MCMR	Medium cost, medium revenue
HR	High revenue	MCHR	Medium cost, high revenue
LD	Low discount rate (d=0.05)	HCLR	High cost, low revenue
MD	Medium discount rate (d=0.10)	HCMR	High cost, medium revenue
HD	High discount rate (d=0.20)	HCHR	High cost, high revenue

Tool Function 1 Example:

Sensitivity of tree growth and profit to coppicing factor

Sensitivity Analysis

↓

Optimization

↓

Operational Change

↓

Longterm Strategy

Objective:

To determine the effect the coppicing factor has on tree growth and total profit.

Significance:

One of the characteristics that makes Eucalyptus appealing for agroforestry is its natural ability to coppice once harvested, producing new stands without the need to plant new seedlings. In addition, because the root systems are established during the tree's initial growth cycle, subsequent coppices tend to get a boost in growth, reaching greater heights and widths in fewer years. As a result, it is important to examine how the GaPP Tool incorporates this coppicing factor and the effect it has on growth and profit.

Result:

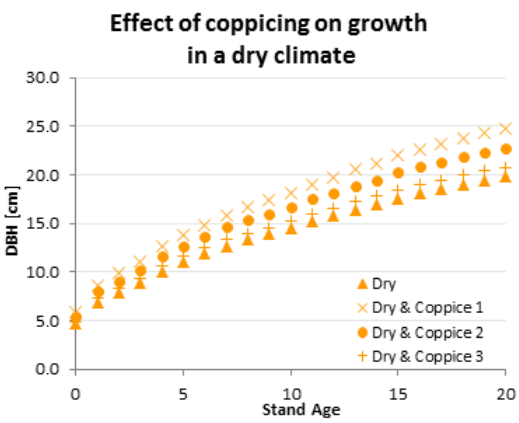
The default coppicing factors currently used by the GaPP Tool are 1.25, 1.15, and 1.05, which represent the 1st, 2nd, and 3rd coppices respectively, and correspond to an initial increase in tree growth of 25% for the 1st coppice and a declining percent increase for the 2nd and 3rd (Cheboiwo & Langat, 2010). Because the coppicing factors are applied to the DBH and stand volume provided by 3PG, the effect on growth is proportional to the coppicing factor, as illustrated in GaPP Illustration 1.5.1. Consistent with the factors, the 1st coppice has the greatest DBH, receiving the largest percentage increase in growth, followed by the 2nd and 3rd coppices, and with the tree's initial growth cycle having the lowest DBH of the four rotation periods.

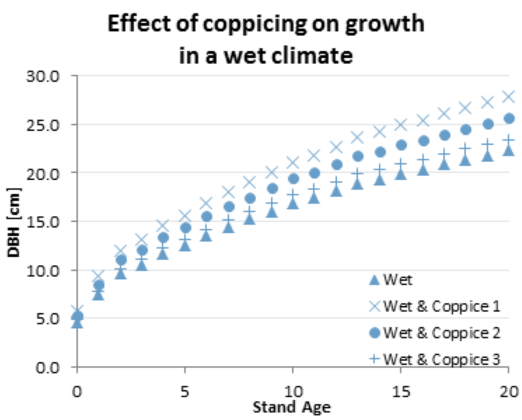
Next, for a product whose profit is determined by the stand volume, such as fuelwood, the effect of the coppicing factor on profit is the same as growth, yielding the greatest profit in the 2nd rotation period when the stand volume is greatest, followed by the 3rd and 4th rotation periods and with the 1st rotation period generating the lowest profit of the four (see GaPP Illustration 1.5.2). On the other hand, for a product such as transmission poles, whose profit is calculated by tree rather than by volume and requires a minimum DBH before it can be sold on the market as that product, the coppicing factor can have a much more profound effect on profit. As can be seen in GaPP Illustration 1.5.2, in a dry climate, transmission poles are not a profitable product selection in the 1st and 4th rotation periods because they do not reach the minimum DBH required for transmission poles.

In the 2nd and 3rd rotation periods, however, due to the increase in growth provided by the coppicing factors, the stands reach the minimum DBH required for transmission poles and as a result, yield a substantial profit. By contrast, for the wet climate, the coppicing factor has zero effect on total profit because the tree stands already reach the minimum DBH required for transmission poles in the first rotation period and therefore do not receive any extra financial benefit from the boost in growth provided by the coppicing effect.

GaPP Illustration 1.5.1
Sensitivity of tree growth to coppicing factor

The effect of coppicing factor on growth for a dry (left) and wet (right) climate with a





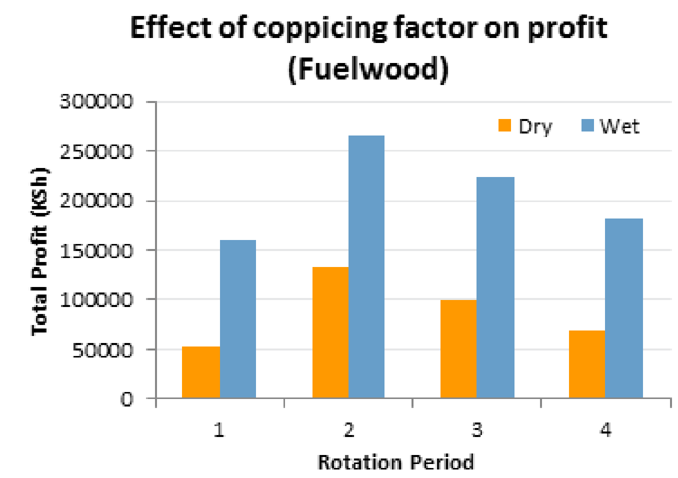
> The additional profitability of coppicing can be profound, but the degree is dependent on the scenario.

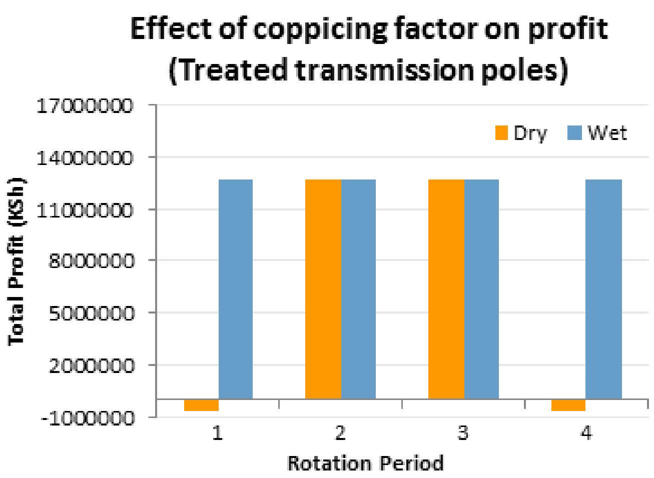
Management Implications:

As demonstrated in GaPP Illustration 1.5.2, coppicing can have a substantial effect on total profit depending on the scenario, due to its influence on growth and consequently, product selection. For this reason, it would be wise for KOMAZA to refine the coppicing factor to its individual sites, possibly through monitoring, so that the GaPP Tool does not overestimate (or underestimate) tree growth in the 2nd, 3rd and 4th rotation periods; such an over- or underestimation could have a huge impact on the optimal harvest age and resulting profit predicted by the tool.

Recommendations:

Our single biggest suggestion would be to collect more accurate information on harvest costs. While conducting the research for this project, we had the most difficulty finding data regarding the costs associated with harvest, including equipment rental, processing, harvest costs for different products, treatment costs for different products, and the cost of logistics for moving the products to certain markets. The inputs we used for these sections were from various sources that ranged from US to Indian markets. Therefore the harvest cost should be assigned a high priority for data collection.





GaPP Illustration 1.5.2 Sensitivity of profit to coppicing factor. The effect of the coppicing factor on total profit when harvesting for fuelwood (left) and for treated transmission poles (right) under both dry and wet climates. A low cost, medium revenue scenario was used and both products were harvested at age 20 for all four rotation periods.

Tool Function 2 Example:

Determining optimal harvest age to maximize profit or NPV for all products

Sensitivity Analysis

↓

Optimization

↓

Operational Change

↓

Longterm Strategy

Objective:

To determine the maximum profit and NPV by optimizing harvest age and product selection when considering all possible product choices under different cost, revenue and climate scenarios.

Ksh 0-3.8 mil

The range of expected optimal profit across all scenarios in a dry climate.

Significance:

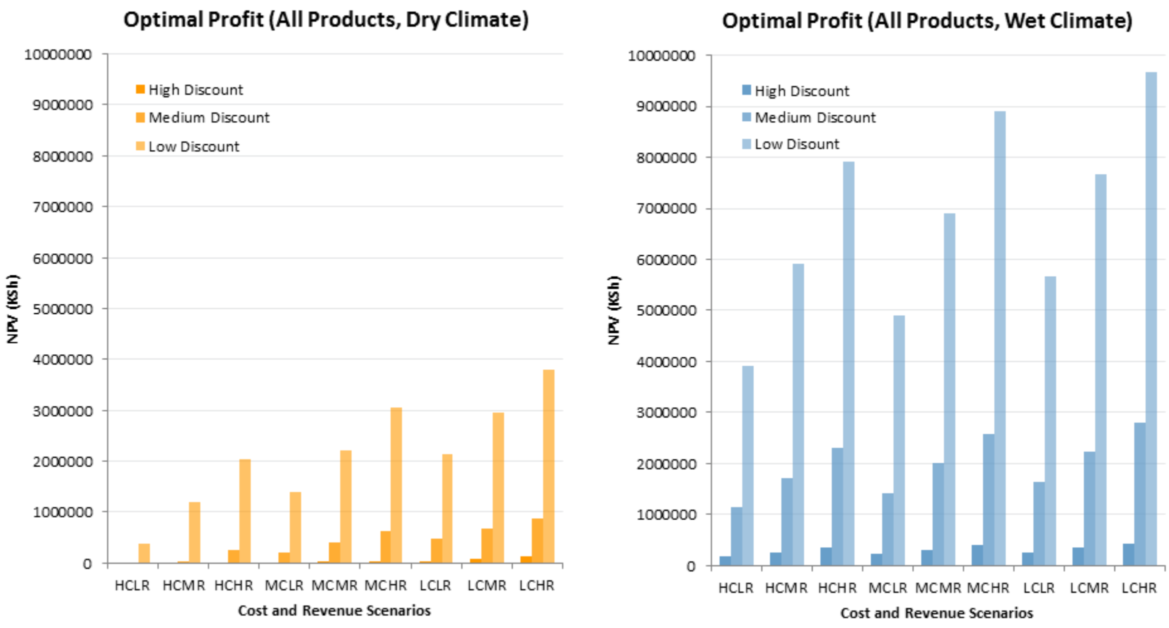
The use of the GaPP Tool demonstrated in this example is likely to be one of the most frequent uses of the tool by KOMAZA. By allowing the tool to maximize profit and NPV by optimizing harvest age under multiple scenarios at once while considering all product choices, KOMAZA can both match different scenarios to specific sites, informing site-specific harvest decisions, and also look for patterns that inform broader management decisions.

Result:

The maximum NPV for dry and wet climates under all cost and revenue scenarios, for all discount rates, and allowing the model to select any of the six products KOMAZA is considering, is displayed in GaPP Illustration 2.2.1. Whereas fuelwood only produced a positive NPV in low cost scenarios (refer to Supplemental Materials - All Examples, 2.1), when all product options are considered, medium and high costs scenarios produce a positive NPV depending on whether the climate is wet or dry, and which discount rate is most probable. For instance, in the dry climate scenario, the site produces a positive NPV for all cost and revenue combinations when the discount rate is low (see GaPP Illustration 2.2.1). This is because for a low discount rate, the optimal harvest age is 19, at which age the stand reaches the minimum DBH for transmission poles in both the 2nd and 3rd rotation periods, yielding higher total profit and positive NPV.

For medium and high discount rates, however, the harvest age is shifted earlier, to age 16 (only yielding transmission poles in the 2nd rotation period) and for some cost and revenue combinations, the optimal harvest age is 2, at which point the model selects roundwood as the most profitable product. In contrast, because the wet climate reaches the minimum DBH for transmission poles at age 20 in the first rotation period and all subsequent rotation periods due to the coppicing factor, the optimal harvest age for the wet climate is always age 20 no matter the

GaPP Illustration 2.2.1 Determining maximum NPV with all products available for selection. Maximum NPV when considering all products for dry (left) and wet (right) climates. Includes all cost and revenue scenarios and discount rates.

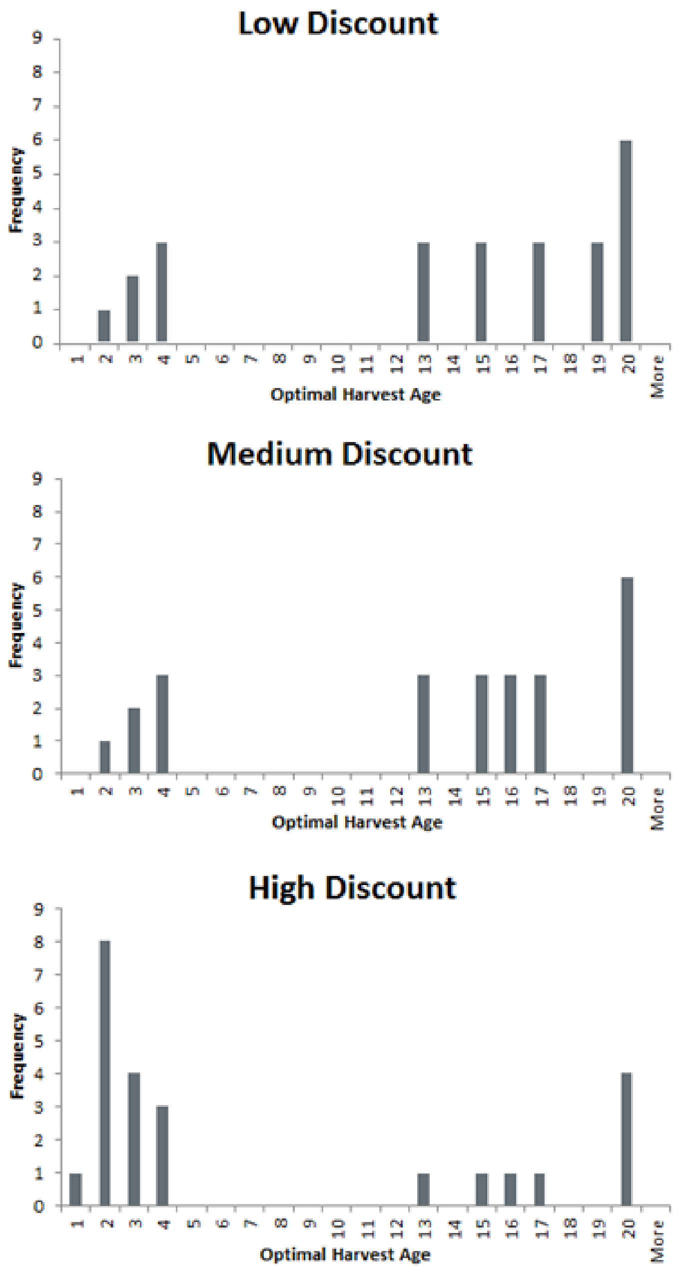


cost and revenue scenario.

The discount rate's effect on optimal harvest age when all product choices are considered is demonstrated in more detail in GaPP Illustration 2.2.2. Unlike GaPP Illustration 2.2.1 which features all cost and revenue scenarios for dry and wet climates, GaPP Illustration 2.2.2 shows the optimal harvest age distribution for all low cost scenarios (LCLR, LCMR, LCHR) for all nine soil fertility and climate scenarios. The low cost scenarios were used because every revenue and climate scenario yielded a positive NPV. As can be seen in GaPP Illustration 2.2.2, there is a very distinct bimodal distribution of optimal harvest age. This is due to product selection. For less productive sites, the optimal harvest age is between 1 and 4 years, selecting roundwood or a combination of roundwood and charcoal as the most profitable products. For more productive climates, the optimal harvest age is between age 13 and 20, when transmission poles or a combination of transmission poles and charcoal are the most profitable products. As expected and shown in previous examples, the optimal harvest age is concentrated around earlier ages for higher discount rates.

Management Implications:

This example illustrates how the optimal harvest age and resulting profit and NPV are influenced by a complex suite of variables including discount rate, climate, soil fertility, cost and revenue. Specifically, discount rate can be very deterministic in whether a site produces a positive NPV under certain conditions. For example, in the case of the dry climate featured in GaPP Illustration 2.2.1, the site yielded a positive NPV for a low discount rate under high cost scenarios, but not for a high discount rate. These patterns are important for KOMAZA to recognize as it may affect its strategy with respect to its farmers' discount rates.



GaPP Illustration 2.2.2 Determining optimal harvest age with all products available for selectionOptimal harvest age distribution when considering all products based on discount rate. Includes all low cost scenarios (LCLR, LCMR, LCHR) for all nine climate and soil fertility scenarios.

> Optimal harvest age can vary widely as a function of product, discount rate, climate, and site parameters.

Tool Function 3 Example:

Comparative analysis of maximum profit for treated poles versus untreated poles

Sensitivity Analysis

↓

Optimization

↓

Operational Change

↓

Longterm Strategy

Objective:

To compare maximum profit and NPV for treated and untreated transmission poles for different market prices and harvest costs.

Significance:

This type of analysis shows which product will be more profitable for different combinations of market price and harvest cost, if other parameter values are certain.

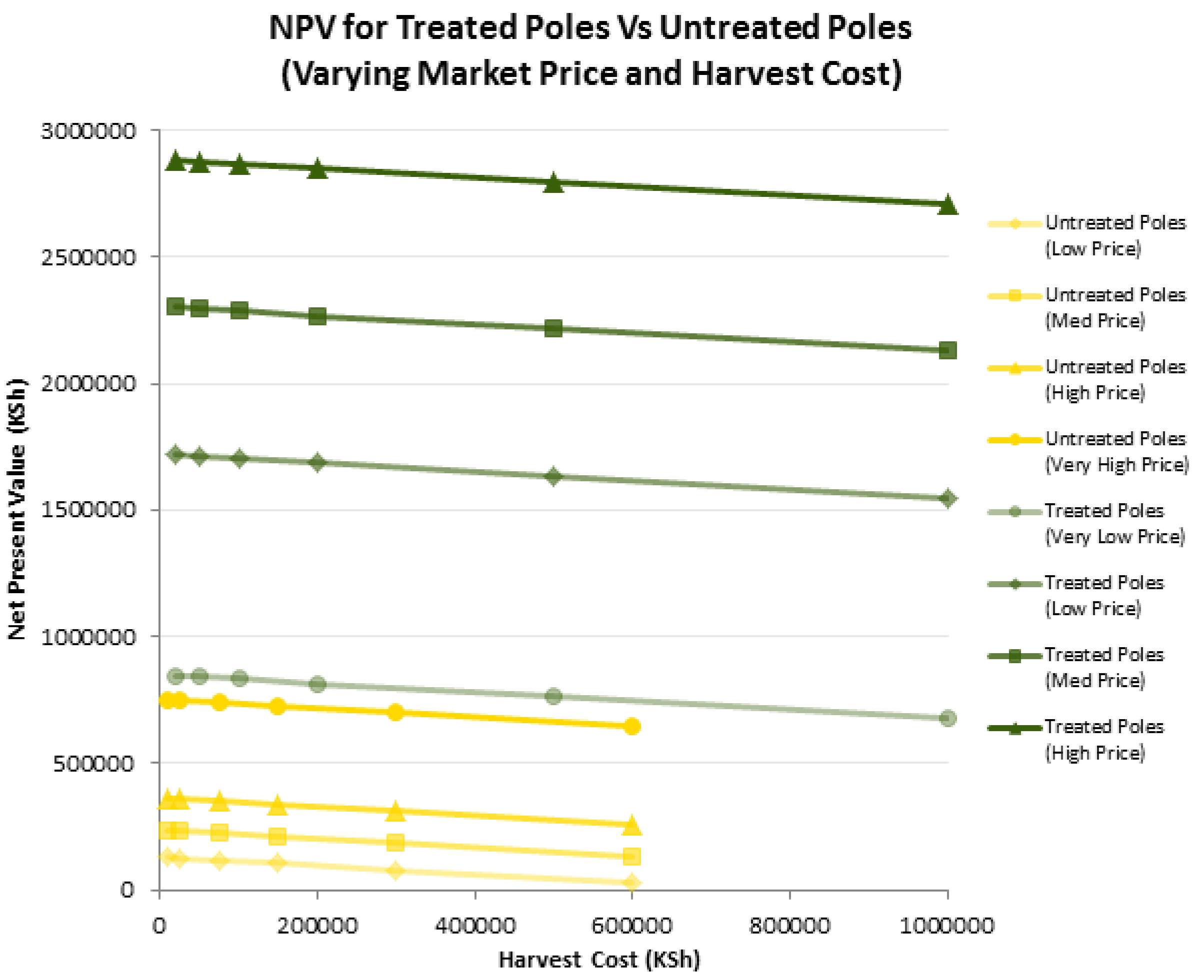
Result:

The GaPP tool was used to find the maximum profit and NPV assuming a wet climate and a medium discount rate for treated or untreated transmission poles, while varying the harvest cost and market price. Initial and annual costs were assumed to be low. For untreated poles, the harvest cost was varied between 10,000KSh and 600,000 KSh. Since treated transmission poles require additional processing and treatment costs, harvest cost values were varied between 20,000KSh and 1,000,000KSh. Default high, medium, and low market prices were used for each product. These are shown in GaPP Illustration 3.2.1 as the top three lines for treated poles and the bottom three lines for untreated poles. For these market prices and harvest costs, treated transmission poles will always have a higher profit and NPV. If the market price for untreated transmission poles is double the high default value and if the market price for treated transmission poles is half the low default values, the most profitable product then depends also on harvest cost.

Management Implications:

If KOMAZA selects a product, such as transmission poles, it may have an additional choice regarding whether to further treat or process the product to add value. The analysis shown in this example will allow our client to analyze the maximum profit and NPV for different treatment options under a variety of market price and harvest cost combinations. The results of this example, shown in GaPP Illustration 3.2.1, suggest that only in a market with a price for untreated poles that is double the highest price found in the literature and a price for treated poles that is half the lowest price found in the literature will untreated poles be more profitable (and only under certain harvest cost combinations (Cheboiwo, 2009). If KOMAZA runs a similar analysis it can determine which product treatment will be most profitable, given likely combinations of market price and harvest cost. Once a product treatment has been selected, KOMAZA can then focus on operational changes that can lower the harvest cost, such as purchasing equipment rather than renting it, or increasing the market value by transporting products to more profitable markets. This analysis can be performed for any product with separate processing options.

> "...KOMAZA can analyze the max profit and NPV for different treatments under a variety of market price and harvest cost combinations."



GaPP Illustration 3.2 Optimal profit for treated poles versus untreated poles. Optimal NPV (d=0.10) in a wet climate for treated and untreated transmission poles, varying harvest cost and market price.

Tool Function 4 Example:

Evaluating possible effects of climate change on growth and profit

Sensitivity Analysis

↓

Optimization

↓

Operational Change

↓

Longterm Strategy

Objective:

To investigate the potential impacts of climate change on tree growth and profit in order to inform future management strategies in adapting to climate change.

Significance:

For KOMAZA's business to be sustainable in the long-term, KOMAZA will need to be able to adapt to climate change. Although it is uncertain what form climate change will take in the region, the GaPP Tool can be used to model potential climate change scenarios to provide a preliminary look at how climate change will affect KOMAZA's farms and general operations.

631 mm

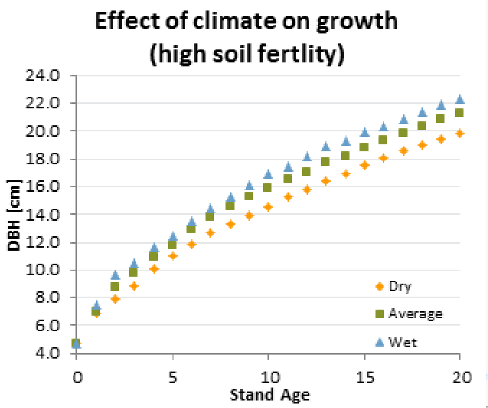
Average annual rainfall during a dry year. Growth rates are predicted to be 20 cm at year 20.

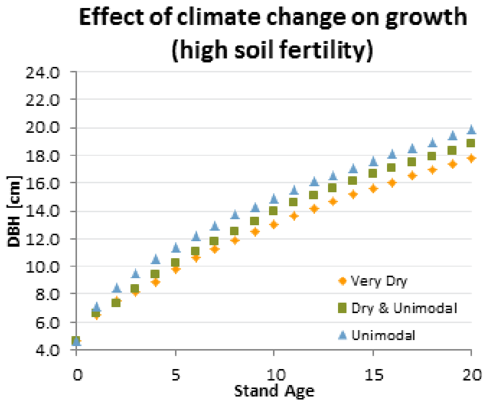
956 mm

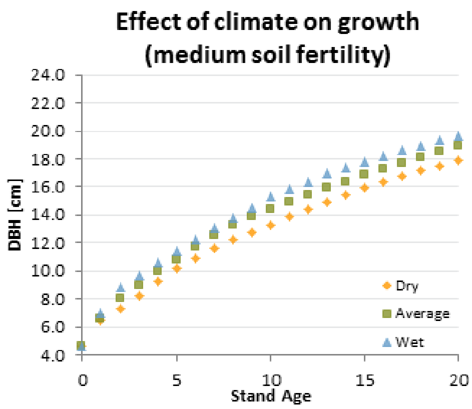
Average annual rainfall during a unimodal year. Growth rates are still predicted to be 20 cm at year 20.

Result:

Three climate change scenarios were modeled in this analysis: a very dry climate (CC1), a unimodal precipitation distribution, where there is only one annual rainy season instead of two distributed throughout the year (CC2), and a dry climate with a unimodal precipitation distribution (CC3). The first, an extremely dry climate, was chosen because we found that Mombasa had experienced seven of the driest years on record in the 2000s. We also simulated a switch to a unimodal precipitation pattern, because some Global Climate Models have predicted a switch to unimodal rains for the region (Dinar, Benhin, Hassan, & Mendelsohn, 2012). The very dry climate is composed of years whose total annual precipitation values are in the bottom 2% of the precipitation dataset. The unimodal climate is made from years with both high seasonality (i.e. 77-84% of the precipitation occurs during the rainy seasons) and high modality (i.e. 76-90% of the rains that fall during the rainy season occur during only one of the rainy seasons); these years were all "average" or "wet" years. Finally, the dry and unimodal climate consists of "dry" years with high seasonality (70-76%) and high modality (70-82%). The effect of these three climate change scenarios on tree growth







GaPP Illustration 4.1.1
Evaluating possible effects of climate change on growth

The effect of climate change on tree growth given a soil fertility rating of 0.7 (top) compared with a sensitivity analysis of tree growth to climate for soil fertility ratings of 0.7 (3rd) and 0.5 (bottom).

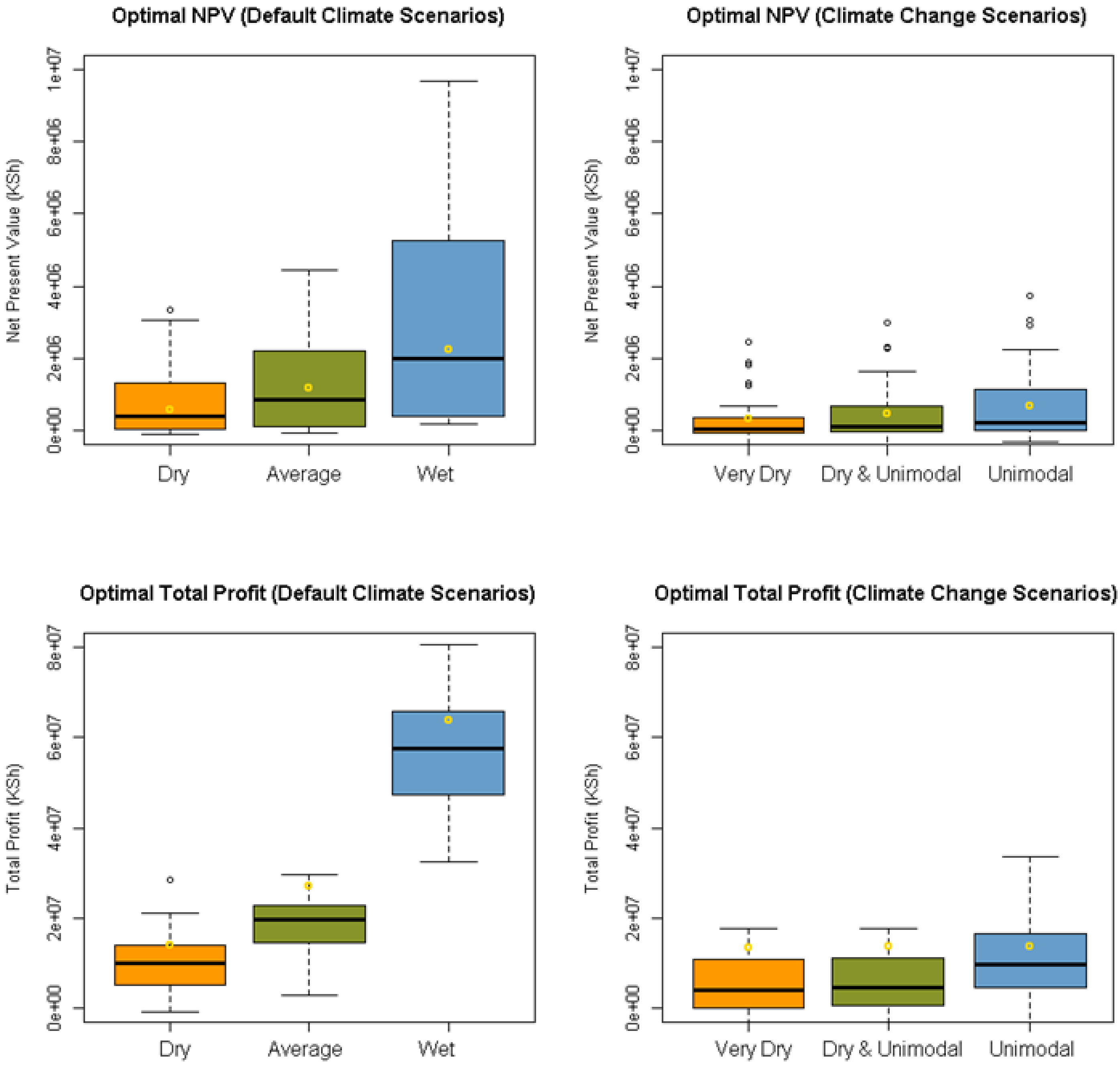
is displayed in GaPP Illustration 4.1.1.

Not surprisingly, the very dry climate, which averages 457 mm of precipitation a year, is the least productive climate, producing stands with a DBH of 17.8 cm at age 20, 2 cm lower than the DBH at age 20 for our default dry climate scenario. What is particularly interesting, however, is that the unimodal climate, which averages 956 mm of precipitation a year, produces the same DBH at age 20 as the default dry climate, which only averages 630 mm of precipitation a year. This result indicates that tree growth is not only dependent on total annual precipitation but the distribution of precipitation throughout the year. Also interesting to note, the resulting tree growth under climate change for a site with our default soil fertility rating of 0.7 is extremely similar to the tree growth for a site with a soil fertility rating of 0.5 for our default dry, average and wet climates (see GaPP Illustration 4.1.1).

The effect of these climate change scenarios on both maximum total profit and NPV was also investigated and shown in GaPP Illustration 4.1.2. In addition to the boxplots showcasing the range of profit for each climate scenario (given all combinations of cost, revenue and discount rate) yellow points are also plotted in GaPP Illustration 4.1.2 to indicate where the low cost, medium revenue and medium discount rate scenario (considered our best guess at parameter values) falls within that range. Consistent with the growth results, the CC2 scenario is most comparable to the dry climate in terms of total profit while the CC1 and CC3 scenarios are less profitable overall. When comparing all the scenarios' NPVs, however, all climate change scenarios' interquartile ranges and median NPVs are lower than that of the dry climate. In addition, the climate change scenarios have higher incidence of negative total profit and negative NPV than the default climates and some of the higher NPV points for the climate change scenarios are considered outliers.

Management Implications:

As KOMAZA crafts long-term management strategies, it is important that it consider the impacts of climate change on its farms and operations, and create a plan to adapt to these impacts. As the preliminary results from this example demonstrate, sites could average 2 cm less growth per tree under climate change conditions compared to the present climate, and as a result, yield lower profits. The results also indicate that this decrease in productivity may be comparable to a decrease in soil fertility rating from 0.7 to 0.5 under current climate conditions. While preliminary, this outcome offers two important insights: (1) with climate change, even KOMAZA's most fertile sites may see profits comparable to today's less fertile sites, and (2) KOMAZA can use today's less fertile sites to inform best management practices and prepare for similar conditions in the future. The outcomes of this type of analysis can help KOMAZA scale up its operations in a sustainable way, by adding new sites that are most likely to remain profitable under climate change scenarios. Since KOMAZA's primary goal is poverty alleviation, they may still choose to scale up to sites with low productivity. However these sites may need to be offset with more productive sites to maintain long-term financial sustainability. An additional concern is how climate change will affect global markets for wood products. While KOMAZA will be selling products to local markets that will likely be insulated from changes in the global market, the possibility of declining market prices due to increased global productivity should be incorporated into its long-term strategic planning.



GaPP Illustration 4.1.2 Evaluating possible effects of climate change on profit. Optimal NPV and total profit for the default climate scenarios (dry, average, wet, FR=0.7) and new climate change scenarios. Each boxplot is made from 27 data points – all nine cost and revenue scenarios for all three discount rates. The yellow points represent what is considered our best guess or default scenario – low cost, medium revenue and medium discount rate.

> "A shift from bimodal to unimodal rain has an almost identical impact on growth as a drought."

Discussion

The GaPP Tool takes the first steps towards [or: Our demonstrations of the GaPP Tool indicate that it is clearly capable of] fulfilling KOMAZA's need for better information the expected tree growth and profitability of their efforts. Builds on already in-use 3PG, adopts Profit to provide a more comprehensive analytical tool. This project developed a tool to 1) integrate more accurate inputs, 2) have a user-friendly interface, and 3) offer analyses across multiple planning horizons. With this information KOMAZA will be able to better manage the expectations of their farmers and investors, and gain better financial stability through an improved decision-making process.

Takeaways

KOMAZA faces the dual issues of a lack of information and a lack of resources that prevents them from strategically ensuring their financial sustainability. However, there are often inherent tradeoffs for improving both of these issues. For instance, a certain amount of resources are needed in order to gain more information. Similarly, resources spent on operations rather than information gathering may prevent KOMAZA from optimizing their management practices. The GaPP Tool provides a way to systematically analyze the trade-offs associated with improving each of their two primary issues.

Our initial implementation of this tool shows that there is not a one-size fits all solution for management decisions of different sites. The optimal harvest age, product selection, and operational decisions are likely to change under different scenarios, as was seen consistently throughout the examples. This suggests that it is important for KOMAZA to be able tailor their plans to individual farms.

At the same time, while decision-making on a site-by-site basis may be beneficial, we recognize that some planning must take place at a large, region scale in order to be effective for the organization as a whole. The GaPP Tool offers analyses across spatial and temporal scales, and gives KOMAZA's planners to have the flexibility to choose the scale they are interested in managing. It is up to their discretion to decide whether a management analysis and decision is appropriate at a regional scale or on a site-by-site basis. This allows them to "steer the boat" through the regional and long-term management decisions while simultaneously addressing immediate management issues through short-term and site-specific planning.

The GaPP Tool provides a clear way to determine the best management option under conditions of uncertainty. This is value because even as inputs continue to be refined through further monitoring and data collection, given the complex number of parameters affecting the agroforestry industry, there is inherent uncertainty within the business. It is therefore important to be able to continue to make reasonable management decision given a certain amount of uncertainty. As we saw in Example 4.1, we can account for uncertainty by integrating over all of the certain parameters and continue to have a distinct best option.

Strengths

The GaPP Tool offers analyses that are relevant to various decision-makers throughout KOMAZA's team, from data collectors to the CEO. The fact that it was created to have a simple, two-page interface therefore is one of its critical strengths. Increased user-friendliness means that less time is needed to understand and adopt the platform, making it more likely that KOMAZA employees will be able to integrate this tool into their decision-making process. This is especially critical because we developed the tool to be address the needs of multiple positions throughout the organization.

Information Manager:

It is valuable for KOMAZA to prioritize future data collection, as having more refined inputs offers more accuracy to the planning process. The sensitivity analysis in Tool Function 1 allows KOMAZA to determine the sensitivity of tree growth and profit to different environmental and market scenarios. The information manager can then use that information to strategically invest KOMAZA's resources in refining inputs that have high uncertainty, high impact, and/or low collection costs in order to systematically improve the precision of the GaPP Tool's results.

Director of Operations:

KOMAZA currently faces uncertainty in the accuracy of its growth predictions, the optimal harvest product, and the optimal harvest age, as well as the value of certain operational changes. First, the tool provides a way to continue to make more well-informed, strategic decisions under conditions of great uncertainty through a probability analysis in Tool Function 2 (the information-poor pathway). Second, once the information manager has added greater certainty to the model inputs, the Director of Operations can use the Tool Function 3 to calculate the expected value of making an operational change on an individual farm or series of farms. The adaptability of the tool is one of the biggest strengths in these analyses for the Director of Operations. As long as a scenario can be translated into model parameters, it is possible to examine how it will impact KOMAZA's profitability. This allows the Director to examine the impacts of different operational options.

CEO/President (Long-term planners):

The 4th tool function expands the scope of analysis to large spatial and temporal scales that are likely to affect KOMZAZA's entire operations, such as climate change, incorporating long-term environmental sustainability, or strategically choosing regions for expansion. This will enable KOMAZA to effectively scale up its business, so that over time it can improve the financial opportunities for as many farmers as possible in an environmentally sustainable way. This closely follows how operational changes were modeled in example 3.1, but this time the change being captured is caused by an external force and requires planning decisions over a much longer time period. It is estimated that KOMAZA's farms could experience drier weather and a shift to unimodal seasonal rainfall, and as Example 4.1 demonstrates, this suggests a reduction in the expected profits of the affected sites. By detailing precisely what likely impact an uncertain phenomenon such as climate change will have on KOMAZA's business, the abstract issue is translated into business terms that are more easily incorporated into a long term management plan needed to guide day-to-day decision-making.

Limitations and Future Directions

Environmental Impacts

Limitations

Although the GaPP Tool provides a host of planning analyses, it is fairly limited in its ability to assess changes in environmental quality. In order for KOMAZA to maintain long-term business and operational sustainability, it will be necessary to address the operations that impact environmental quality as part of its long-term strategic planning. By its nature, eucalyptus agroforestry will have impacts on the environment, resulting in some environmental improvements and some degradation. For instance, eucalyptus, as with all trees, uses water which could otherwise be utilized locally for crops, by downstream communities, or for biodiversity habitat (KFS, 2009). At the same time, it has been shown that in many situations that eucalyptus plantations can stabilize denuded soils and attenuate wind and rain energy, thereby reducing soil erosion.

While the GaPP tool optimizes operations for maximum profit or NPV derived from eucalyptus wood products for KOMAZA's farmers, it does not account for effects on other parties or environmental costs and benefits associated with the agroforestry operations. If KOMAZA determines the optimal management strategy which yields the maximum total social and environmental benefits relative to total costs, it can be beneficial to conduct a systematic cost-benefit analysis of alternative management strategies. However, developing a cost-benefit analysis is a complicated process that requires extensive data sets, complex modeling of environmental systems, and in-depth economic analyses, and may not be the ideal tool given KOMAZA's current needs and lack of resources. Once KOMAZA becomes well established and wishes to further improve its long-term sustainability strategy, a cost-benefit analysis can provide some guidance to reach that goal. Furthermore, due to the complexity and uncertainties associated with agroforestry cost-benefit analyses, especially resulting from non-market valuation, the outputs should be regarded as one part of a larger decision-making process.

Future Directions

Expanding the tool to model environmental impacts will allow KOMAZA to weigh the trade-offs between profitability and environmental impacts. To reach KOMAZA's goal of making more well-informed decisions, the next step would be to incorporate a way to quantitatively measure the environmental impacts of KOMAZA's forestry practices. Currently the GaPP Tool enables KOMAZA to help farmers establish a forestry strategy that increases farmers' profits, but

To begin to incorporate environmental quality into their strategic planning, it is recommended that KOMAZA identify all impacts associated with its operations, including those that improve and degrade the environment. The United Nations Development Programme (UNDP), with Global Environmental Facility (GEF), has developed a framework for identifying ecosystem functions and services, and assigning economic values to those services. The process includes a cost-benefit analysis used to compare the private, social and environmental costs and benefits associated with alternative management strategies (Dinar et al., 2012). There are several places where the 3PG model in particular can be expanded to begin to capture the environmental impacts of the microforestry plots, including the measurement of soil erosion rates, carbon sequestration, and water availability.

KOMAZA should also identify stakeholders and the system boundary of the analysis. For instance, if it is interested in improving the livelihood of all people in Ganze District, Kenya, then the district would be the system boundary. KOMAZA can then identify critical ecosystem functions and services. These will include provisioning services, such as wood and food production, as well as regulating services, such as carbon sequestration, hydrologic regulation, and erosion control, and may also include ecosystem services such as biodiversity. Due to limited resources, KOMAZA should identify the environmental issues that are most relevant to the region, and the drivers of those problems. For example, desertification is a major problem in the region, driven by deforestation and subsequent soil erosion.

Next, KOMAZA should choose indicators of the environmental degradation that can be easily measured. Indicators are then selected for each service and the ecosystem services are quantified. Then, if possible and appropriate, these services are assigned a monetary value. If there is a lack of time, funding, or expertise needed for a quantitative analysis, it can qualitatively analyze its operations to assess how it likely affects the environment. Once impacts are quantified, KOMAZA's long-term strategies can be altered to address these issues.

The final step is the most complicated, involving the modeling of changes in ecosystem function and service as a result of changes in management. Ultimately, if all steps are completed, KOMAZA can be informed as to which management strategy is socially optimal, yielding the most benefits to all stakeholders with the fewest costs. When attempting to mitigate environmental impacts, KOMAZA may be faced with a trade-off between profitability and environmental quality. It will be a normative decision as to what combination of profitability and environmental quality KOMAZA is willing to accept in order to maximize long-term profitability while minimizing negative environmental and social externalities.

Model Validation

Limitations

The GaPP Tool is in its first phase of development, and has not yet been validated to ensure that the relationships in the Profit Model are accurately captured. Furthermore, there are inherent uncertainties in the strength of 3PG to accurately model growth. Although the methods used to develop the model and determine many of the inputs were rigorous, model validation is an important step in tool development. Therefore, we caution that while the GaPP Tool offers clarity in the planning process, the answers it gives are sensitive to the assumptions in the model and the precision of the inputs.

Employees at KOMAZA's nursury and X-farm preparing new seedilings

Future Directions

As part of the model validation process, KOMAZA will need to continue to refine the data inputs, and also validate the model through its own observations. A number of the inputs were determined by our best possible estimates based on literature reviews. However, KOMAZA should continue to tailor the GaPP Tool to its region and market by collecting information on these inputs to gain greater certainty in the data. These inputs include the discount rate, precipitation data, market data, soil fertility, minimum DBH needed for a product type, and the vegetation parameters for alternate tree species it is interested in cultivating in the future.

Unforeseen Events

Limitations

It is important to be aware that there are potentially unforeseen events that we have not yet considered that affect profitability in a way that the GaPP Tool may not be able to account for, such as a pest blight or a change in market demand. The Tool was created to be adaptable, however, and so if KOMAZA can quantify the impacts of the unanticipated events in terms of the model parameters, the GaPP Tool provides a way for the organization to incorporate the unexpected into its planning process. For instance, if civil unrest north of Ganze causes KOMAZA to seek a different market further away, it can incorporate additional delivery costs into the harvest costs.

Future Directions

In order to maximize the flexibility and adaptability that enables further analyses under unforeseen conditions, the GaPP Tool can continue to be adjusted. Refining the Profit Model further could be particularly beneficial, as monetizing an unanticipated event is a relatively easy way to analyze its impacts and respond through the management process. Adjustments to consider include altering the cost functions to make them more dynamic and more sensitive to time and growth. In order for this step to yield meaningful results, however, it would be beneficial to make this adaptation after more accurate cost data has been acquired. As of now, annual costs are constant over the planning horizon, but the tool may benefit in the future from the option to manually input all annual costs.

Coppicing Effect

Limitations

The model currently has a set length for each rotation period. Because the coppicing effect increases the growth rate, however, the time needed to reach the same size wood product decreases with each new rotation period. The coppicing effect is accounted for in the profit model by allowing more high-value products to be achieved earlier due to the accelerated growth rate. The model is not currently coded to analyze how much earlier a single product could be harvested in each successive rotation period, although KOMAZA could run that analysis manually by altering the parameters systematically.

Future Directions

Since having a dynamic rotation period that allows coppicing impacts to be examined in a variety of ways is useful to KOMAZA, we recommend that they continue to expand the model. Specifically, the R code will need to be adjusted to allow rotation period length to change between rotation periods during optimization to capture the effect of coppicing across the same product type.

Sensitivity Analysis

Future Directions

Given both the current needs of our client combined with computational limitations, we chose to examine specific parameters and parameter ranges we believe are most sensitive for KOMAZA's operations, based on feedback from KOMAZA and insights from the literature. The GaPP Tool can currently test the sensitivity of growth and profit to several parameters at the most. Should KOMAZA be interested in pursuing a more in-depth sensitivity analysis, however, co-varying all uncertain parameters in a Monte Carlo Sampling would offer an exact value of the sensitivity of each parameter. This could be valuable if KOMAZA is interested in examining the interaction between multiple parameters. However, this type of analysis requires a significant amount of computational power, and is most effective with greater certainty in the realistic bounds of the data, so KOMAZA may not find that this type of analysis drastically improves its planning capabilities at this time.

Concluding Remarks

We intend for this tool to allow KOMAZA to expand its' decision-making capacities, as well as free up valuable time and resources for multiple employees. This tool effectively fills a knowledge gap caused by a lack of resources and a lack of experience, and now allows the organization to predict profit on multiple scales despite uncertainty in environmental and market conditions. We expect the improved decision-making capacity will help ensure KOMAZA's financial stability and enable it to invest in other projects and goals, such as incorporating more of their secondary goal of improving environmental sustainability, or focusing on farmer education and awareness. We also expect that maximizing their profitability will assist them in gaining more traction and buy-in among farmers in the region, allowing the organization to extend the positive impacts of their efforts. Ultimately, we believe that the added value to their planning capacities could help KOMAZA achieve financial sustainability and help them provide economic stability to as many farmers as possible in an environmentally sustainable way.

> "Ultimately, this model aims to capture the dynamics between various factors that affect the ultimate profit KOMAZA and KOMAZA's farmers will gain. It serves as a tool to shed more light on the management decisions KOMAZA is faced with throughout its operations."

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Supplemental Materials: Demonstration of the GaPP Tool

Sustainable Microforestry Report, April 2013

Contents

Introduction to This Document

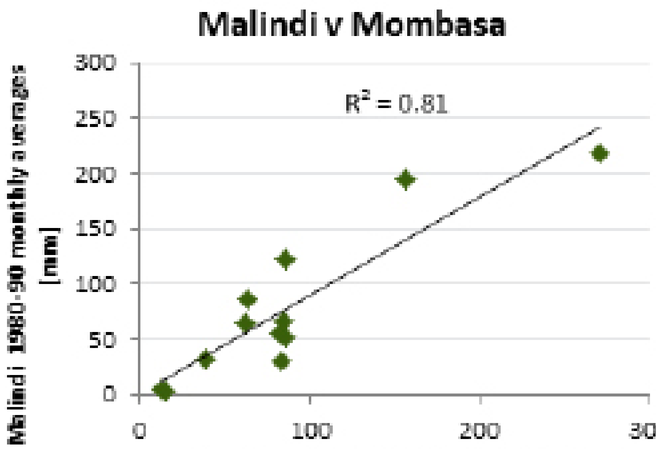
This document provides supplemental materials to the "Sustainable Microforestry: An adaptive management tool for smallholder agroforestry farms in Ganze, Kenya" report. The materials include instructions for further developing the GaPP Tool Inputs, examples of different simulations, the R code necessary to run the simulations, and the appendices. This report is the product of a Masters Project from the Bren School of Environmental Science and Management at the University of California Santa Barbara in April 2013.

Developing GaPP Tool Inputs

Solar Insolation: We maintained the solar insolation range at its current range of 16.24 – 22.00 MJ/m2 (OpenEI, 2013), (Boxwell, 2013) throughout the demonstrations. This approach is reasonable as the inter-annual variation in solar radiation is likely to be small for this region. However, if the user should want to include natural variability within the simulations, historic observation or climate models can be used to allow this parameter to vary from year to year.

Precipitation: Data available from the Ganze District weather stations was limited to a single sample of monthly precipitation records averaged over a decade from 1980-1990 (ISRIC, 2013). In order to gain a more detailed precipitation dataset we examined the precipitation data records available for both Mombasa and Malindi, which are situated almost equidistant south and north of Ganze, and have daily weather records dating back as far as 1957 (NCDC, 2013). The daily records were compiled into total monthly precipitation and then converted into the same units as the Ganze precipitation data (millimeters). The datasets were adjusted to remove years with incomplete precipitation data across all datasets to enable uniform analysis between datasets. The 1980-1990 monthly averages for the Mombasa and Malindi datasets were then compared using a linear regression analysis, and were found to be well correlated (R2 = 0.8111) (Figure 15).

Figure 15. Average precipitation for Malindi and Mombasa



Once a correlation was established between Mombasa and Malindi indicating that there is comparable climate variability across the region, a linear regression analysis was applied to the Ganze and Malindi data, and the Ganze and Mombasa data. They were all found to have high correlations, with the strongest correlation found between the Ganze and Mombasa data (R2 = 0.9156) (Figure 16).

Having established that it is reasonable to use the Mombasa and Malindi precipitation data to create "historic" Ganze yearly monthly precipitation records, we then proceeded to weight the Mombasa and Malindi data to create levels of precipitations reflective of those expected in Ganze. The "historic" Ganze yearly records were based on the linear relationships found between the data and weighted by the R2 values using the equation on the following page.

After generating an "historic" dataset for Ganze, we ran an autocorrelation between the years to determine if one year's precipitation determined the following year's precipitation. We found that there was no significant correlation between the January of one year and

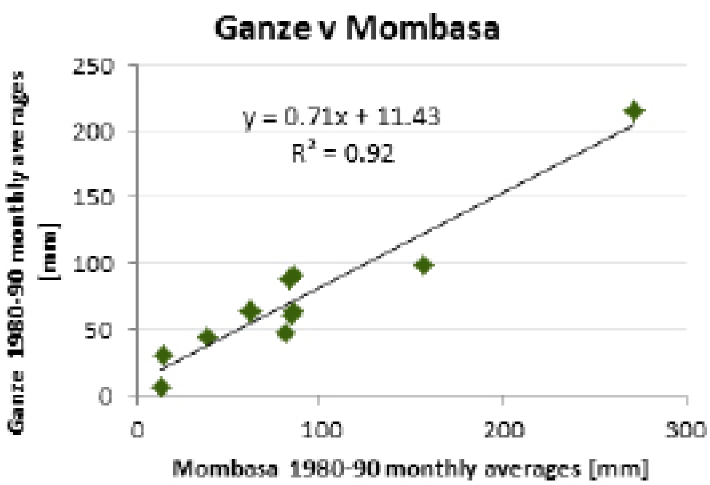
$$Ganze\ Data = (0.6376 * Malindi\ Data + 23.778) * \left(\frac{0.718}{0.718 + 0.9156}\right) + (0.7134 * Mombasa\ Data + 11.428) * \left(\frac{0.9156}{0.718 + 0.9156}\right)$$

the January of subsequent years, indicating that years could be sampled independently from one another. However, given a small sample size of 28 years, we bootstrapped our data by resampling multiple times in order to determine the statistical accuracy of our sample data. The results of the bootstrapping indicated that individual years would not have increased the variability in our dataset. Therefore, we chose to sample individual seasons to preserve continuity between the rainy months and the dry months, yet increase variability in our yearly sample records. This sampling approach proved to be sufficient, yielding a bootstrapped sample with a comparable distribution to our "historic" Ganze dataset (Figure 17). We then characterized our bootstrapped sample years as "dry", "average", and "wet". The dry scenario was created from the years within the first quantile, the average scenario was created from years within the second to third quantile, and the wet scenario was created from years within the fourth quantile.

We also used the bootstrapped data to create new variables that are representative of seasonality and modality, or the distribution of rainfall throughout the year. For instance, Coast Province currently experiences bimodal rainfall, with a "short rains" season and a "long rains" season. These are necessary variables to include because sharp changes in monthly rainfall can strongly impact tree growth (Sands & Landsberg, 2002). Annual variability is also important to capture, as weather and precipitation is highly variable, and a single average per year would not accurately reflect natural variability. We captured seasonality by examining the total percent of precipitation occurring during the rainy seasons. As with total annual precipitation, we divided our bootstrapped data by "high", "medium", and "low" seasonality based on the 1st and 3rd quartiles found in the Ganze seasonality distribution. Modality was created by examining the precipitation occurring during the Long rains (April-June). A representative unimodal system was determined to be one where the percent of rain within the Long rains was very high, with very little rain occurring during the Short rains (Oct-Dec) and vice versa. Bimodal precipitation patterns are represented by years where the percent of precipitation was split evenly between the Long and Short rains.

We examined ten to twenty year periods of time to identify periods that are characteristically dry, average, or wet, and used those periods to develop reasonable precipitation scenarios. Finally, in order to create uncharacteristically dry or wet scenarios, we used the bootstrapped data to create scenarios represented by the extremes of the total annual precipitation distribution. It was important to include these scenarios because, although they are currently rare events, climate change is expected to make more extreme weather conditions occur more frequently (Dinar et al., 2012).

Figure 16. Correlation between Ganze and Mombasa monthly precipitation rates.



The model code currently incorporates the representative dataset in a way that repeats the dataset at the start of each new harvest period. We recognize that it is unrealistic to assume that precipitation patterns would repeat precisely, especially if the trees were harvested frequently. However, because the coppicing effect starts after the first harvest and there is a nontrivial amount of uncertainty and variation between individual trees in how much a tree's volume increases due to coppicing, the impacts of an unrealistically consistent precipitation pattern become negligible.

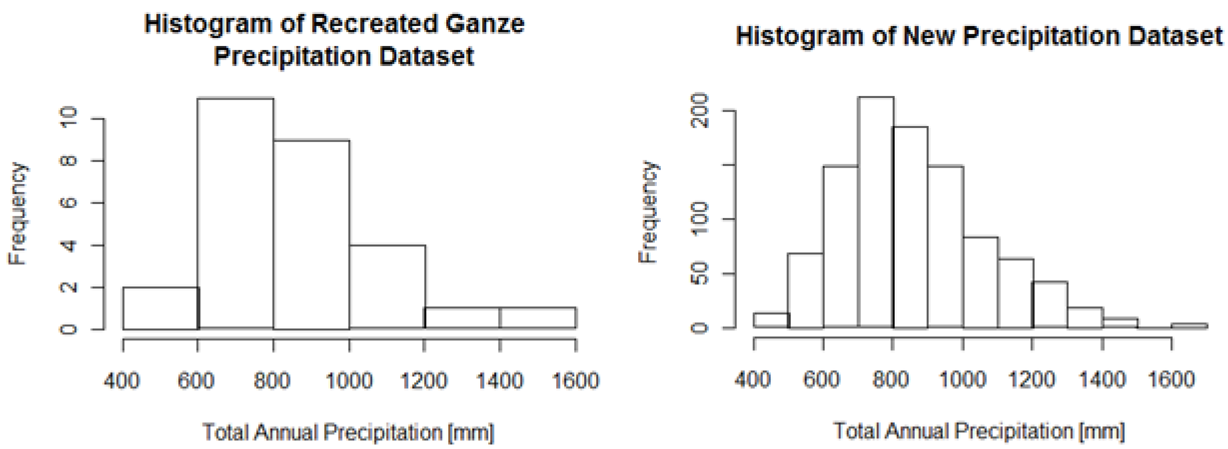
Temperature: We acquired averaged monthly historical data for the Ganze District, but were unable to access the complete record in order to include natural variability into our temperature set (Støwer, 2013). We therefore used the same method for determining the temperature as we did for the precipitation. Both Mombasa and Malindi temperature datasets were compared against the averaged Ganze District temperature and were used to create a long-term temperature data-set weighted to a reasonable range for Ganze District.

We acquired averaged monthly historical data for the Ganze District, but were unable to access the complete record in order to include natural variability into our temperature set (Støwer, 2013). We therefore used the same method for determining the temperature as we did for the precipitation. Both Mombasa and Malindi temperature datasets were compared against the averaged Ganze District temperature and were used to create a long-term temperature data-set weighted to a reasonable range for Ganze District.

Vegetation Parameters: We were interested in examining the impacts a different species would have on growth in order to better understand the model estimates' sensitivity to variation in vegetation parameters, as well as how sensitive the vegetation parameters are to species variability and local site variability.

For the purpose of this paper we chose to examine how the characteristics of a more drought-tolerant species would impact growth, as drought is a consistent issue in the region, and water availability is a limiting growth factor for most species. We therefore simulated a slightly more drought-tolerant tree by altering several key variables associated with drought-tolerance within the vegetation parameters of our original species E. grandis camaldulensis. Specifically, we altered the average monthly root turnover rate (from 0.015 to 0.013), the minimum fraction of NPP to roots (from 0.20 to 0.23), and the ratio net to gross primary production (from 0.47 to 0.49). These parameters are all within realistic ranges based on observed vegetation parameters (TRY, 2013). We also increased the Maximum Available Soil Water (identified as Max ASW in the 3PG model) from 152 to 300, as a more drought-tolerant species characteristically has an increased ability to extract available water from the soil (Borchert, 1994). It should be noted that this is one example of a way to incorporate a different species into the analysis, and there are a number of other vegetation parameters that can be adjusted to capture the unique specifics of other species that a user may be considering.

Figure 17. Comparison of recreated historic Ganze dataset and new Ganze precipitation dataset



All Examples

Tool Function 1: Sensitivity Analysis

Calculating the effect on tree growth, profit, or NPV from a change in one or more parameter values

Example 1.1

Sensitivity of tree growth to climate and soil fertility

Sensitivity Analysis
↓
Optimization
↓
Operational Change
↓
Longterm Strategy

Objective:

To determine the effect of climate and soil fertility on tree growth for E. grandis camaldulensis.

Significance:

Climate (which encompasses both precipitation and temperature) and soil fertility are two of the three 3PG input variables that are varied in this analysis. Additionally, it is reasonable to analyze climate and soil fertility together because of possible interaction effects between the two variables.

Result:

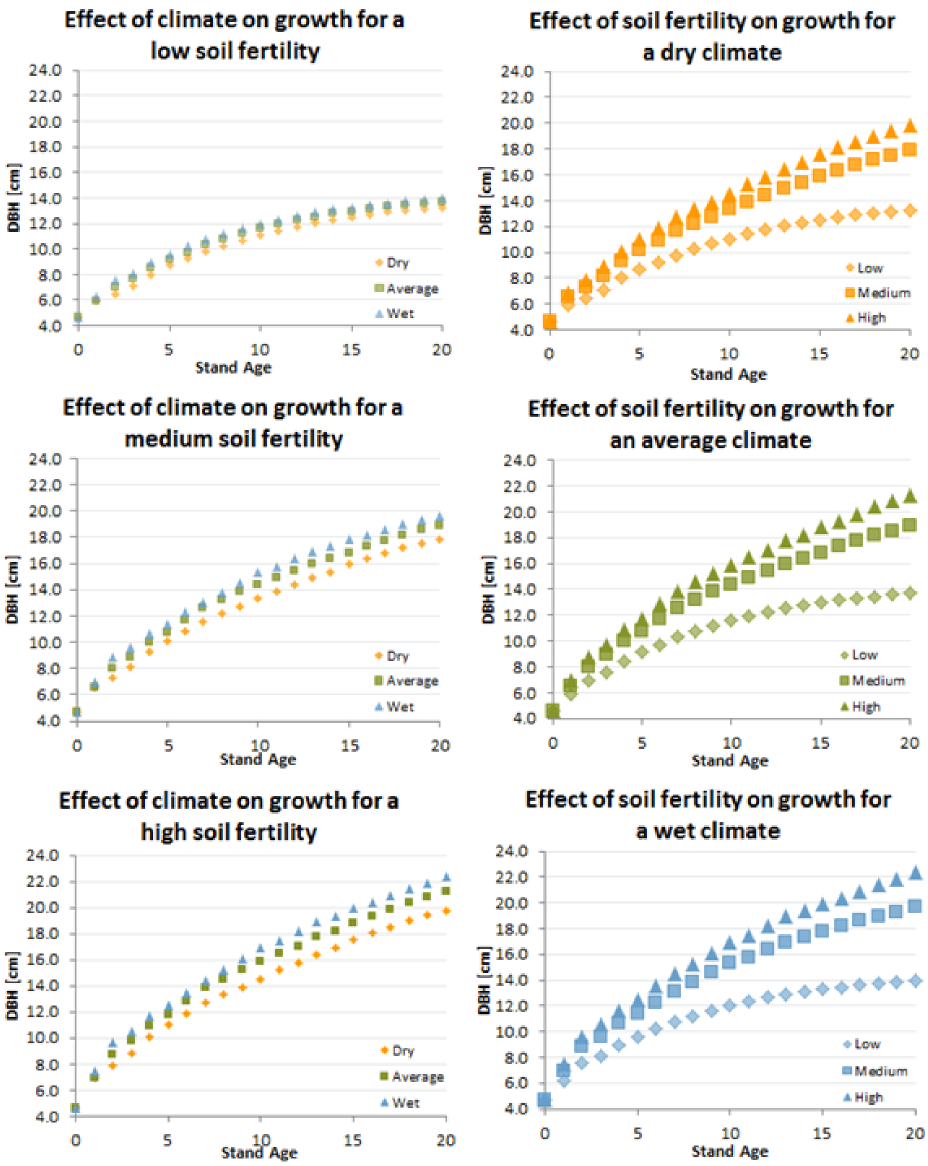
Overall, soil fertility has a greater impact on tree growth than climate, as shown in GaPP Illustration 1.1. The tree growth's sensitivity to climate does, however, increase for sites with higher soil fertility ratings.

Management Implications:

These results indicate that soil fertility rating, and as a result, fertilizer use, is expected to have a large impact on a site's productivity. For this reason, we assume a high soil fertility in the remainder of our demonstration, anticipating that KOMAZA will, to the extent possible, keep their sites fertile by applying the necessary amount of fertilizer. In addition, because soil fertility is a site parameter, fertilizer application rates should be considered on a site by site basis.

Recommendations: Although temperature is a parameter that could be further refined to individual sites in the Ganze District, we determined that it is not a valuable use of resources for KOMAZA for two reasons. First, the net primary production in the region is water-limited, not temperature-limited (Running et al., 2004), meaning the effect of variations in temperature on growth is drowned out by the impacts of other uncertain variables such as precipitation. Second, during our comparison of other weather station data, we found that there is not a large amount of variability in the region, and at most we would expect a change of one and a half degrees. Incorporating site-specific temperature data is therefore not likely to have a large impact on the accuracy of growth outputs. However, because our temperature dataset was created from a weighted estimate of Mombasa and Malindi data, we do recommend further monitoring within Ganze District to confirm that the fabricated dataset is accurate. This can be done easily and inexpensively by either collaborating with the Kenya Meteorological Department, or from recording the daily reports from a weather site like the Norwegian Meteorological Institute's Ganze Station (Støwer, 2013).

> "Soil fertility rating, and therefore fertilizer use, is expected to have a large impact on a site's productivity."



GaPP Illustration 1.1 Sensitivity of tree growth to climate and soil fertilityThe sensitivity of tree growth to climate holding soil fertility rating constant (left) and the sensitivity of tree growth to soil fertility rating holding climate constant (right).

Example 1.2

Sensitivity of tree growth to tree species

Sensitivity Analysis
↓
Optimization
↓
Operational Change
↓
Longterm Strategy

Objective:

To determine the effect that a tree species has on a site's productivity under varying climatic conditions.

Significance:

The tree species (or subspecies) that is selected to be cultivated is the foundation upon which KOMAZA's agroforestry operations are built. It is therefore important for the GaPP Tool to be able to assess the sensitivity of growth (and subsequent profit) to the tree species being cultivated.

Result:

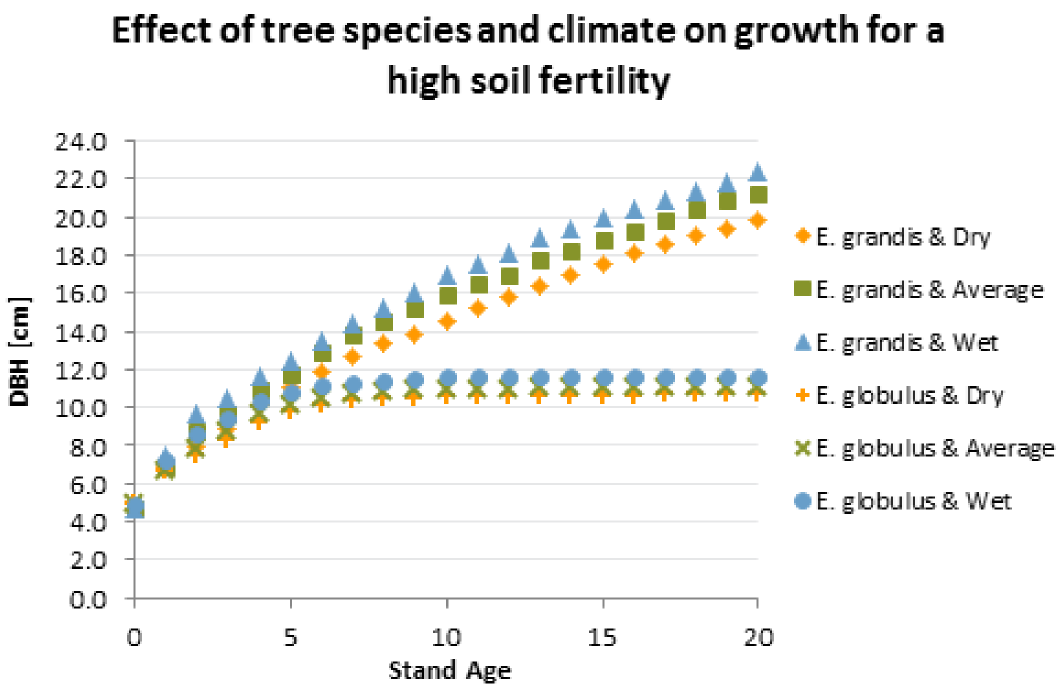
In comparing E. grandis camaldulensis to E. globulus, GaPP Illustration 1.2 demonstrates that the tree species has a significant impact on a site's productivity under the climatic conditions modeled, specifically for stands older than 5 years. This result is consistent with literature which recommends planting E. grandis camaldulensis in the semi-arid lowlands of Coast and Nyanza Provinces, and alternatively, recommends planting E. globulus in the higher rainfall, higher elevation areas of Molo and Nyandarau, Kenya (KFS, 2009).

Knowing that KOMAZA is considering using Melia volkensii in the future due to Melia volkensii's anticipated capacity to better withstand drought conditions, we also used 3PG to test the sensitivity of growth to a theoretical species which we named Species DT (for drought-tolerant). We altered parameters associated with drought-tolerance to create Species DT, including the vegetation parameters minimum fraction of NPP to roots (pRn), ratio net to gross primary production (Y) and average monthly root turnover rate (Rttover), and the site parameter maximum available soil water (Max ASW). Altering these parameters showed very little change in growth for all soil fertility and climate scenarios modeled. Furthermore, while the change in growth was slight, E. grandis camaldulensis out competed Species DT in all scenarios modeled.

Management Implications:

Due to the complexity of vegetation parameters and how they are modeled in 3PG, it is unclear whether the negligible difference in growth between Species DT and E. grandis camladulensis is due to uncertainty associated with the values for the vegetation parameters for Species DT or because E. grandis camaldulensis is extremely competitive in drought conditions. Given the uncertainty of the dynamics at work, it could be very valuable for KOMAZA to work with an ecophysiologist, who could recommend specific values for the vegetation parameters of Melia to be incorporated into 3PG before they invest in a large-scale Melia program.

> "Eucalyptus grandis outcompeted our drought-tolerant tree species."



GaPP Illustration 1.2 Sensitivity of tree growth to tree species. Comparison of E. grandis camaldulensis and E. globulus under varying climate conditions and a constant soil fertility rating of 0.7 to test the sensitivity of tree growth to tree species.

Example 1.3

Sensitivity of profit to discount rate

Sensitivity Analysis

↓

Optimization

↓

Operational Change

↓

Longterm Strategy

Objective:

To determine the effect of discount rate on total profit and net present value (NPV) keeping all other variables constant.

Significance:

KOMAZA's farmers' value-time preference, or discount rate, is likely to have one of the largest impacts on the profitability of their tree lots given its influence over the harvest age. For this reason, it is valuable for the GaPP Tool to be able to model the sensitivity of total profit and net present value to discount rate.

Result:

GaPP Illustration 1.3 demonstrates the effect of discount rate on total profit and NPV for one product (fuelwood), one cost and revenue scenario (low cost, high revenue), and one climate scenario (wet with FR= 0.7). Since fuelwood's revenue is based on the stand volume, fuelwood is most profitable at age 20, when the stand volume is greatest. However, when a discount rate is introduced, even for a low discount rate of 5%, the NPV at age 20 is less than the NPV at age 19. Although total profit is greatest at age 20, due to time preferences the profit is discounted based on the year it is received and worth less in NPV at age 20 than at earlier harvest ages. Therefore, as the discount rate increases, NPV is maximized at earlier harvest ages.

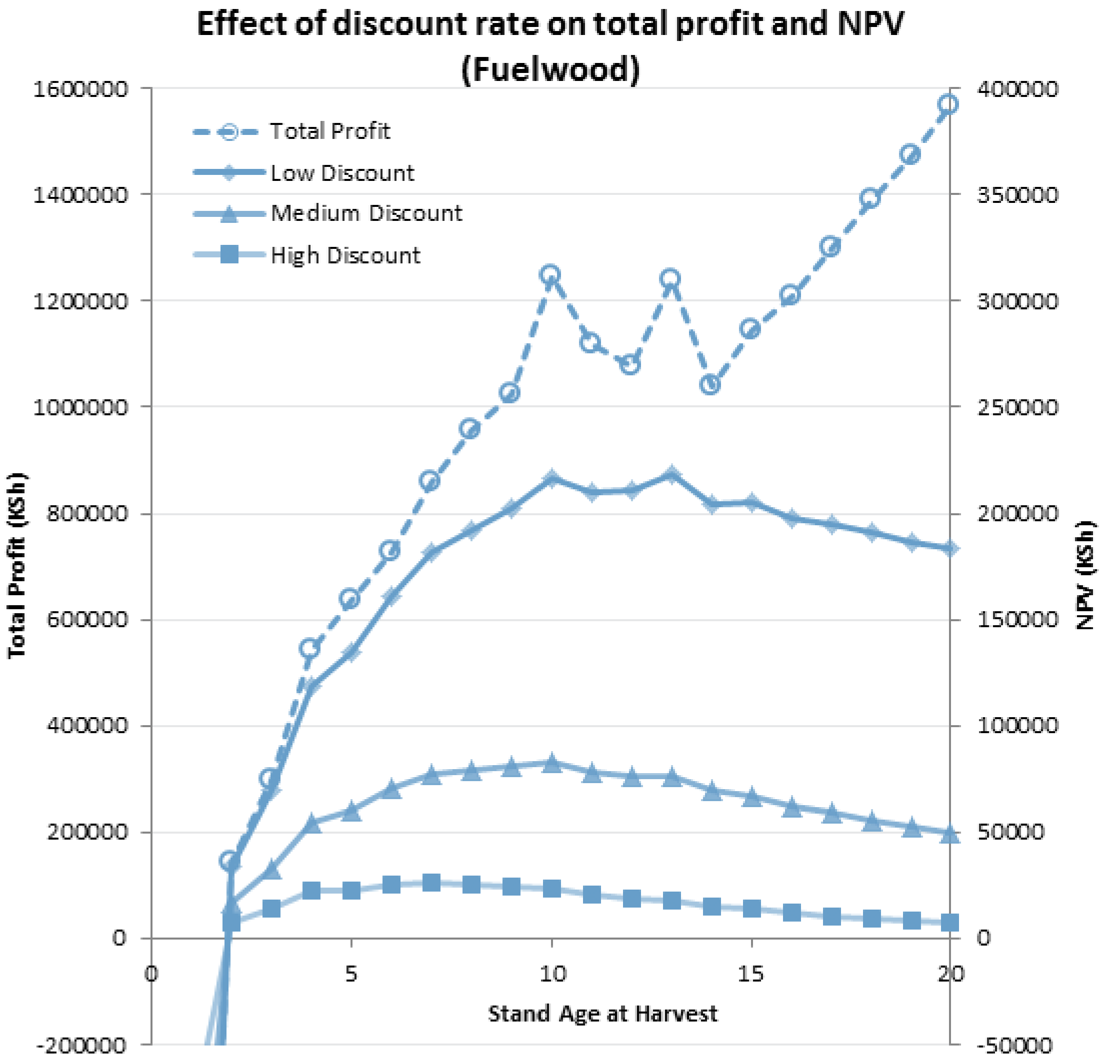
Management Implications:

Since discount rate is critical in determining the optimal harvest age to maximize NPV, it is one of the first variables that KOMAZA should refine to increase the accuracy of the GaPP Tool. A process to refine this parameter value is detailed in the Recommendations section of this report.

Recommendations:

Our single biggest suggestion would be to collect more accurate information on harvest costs. While conducting the research for this project, we had the most difficulty finding data regarding the costs associated with harvest, including equipment rental, processing, harvest costs for different products, treatment costs for different products, and the cost of logistics for moving the products to certain markets. The inputs we used for these sections were from various sources that ranged from US to Indian markets. Therefore the harvest cost should be assigned a high priority for data collection.

> "Discount rate may be one of the first variables KOMAZA would want to refine through data collection."



GaPP Illustration 1.3 Sensitivity of profit to discount rate. The effect of discount rate on total profit and net present value (NPV) for fuelwood under a low cost, high revenue, wet climate, FR=0.7 scenario. Total profit in Kenya shillings is displayed on the left hand Y axis and NPV in Kenya shillings for all three discount rates is shown on the right hand Y axis.

Example 1.4

Sensitivity of profit to harvest costs

Sensitivity Analysis

↓

Optimization

↓

Operational Change

↓

Longterm Strategy

Objective:

To determine the effect of harvest costs on the maximum NPV, while optimizing harvest age and keeping all other variables constant.

Significance:

From a review of journal and industry articles (Langat & Cheboiwo, 2010), (NABARD, 2013), it was determined that harvest cost (which includes all costs associated with harvesting, processing, transporting, and selling the products) was the parameter with the most uncertainty. Due to this uncertainty, the following analysis was performed to determine the likely range of NPV for a wide range of harvest costs.

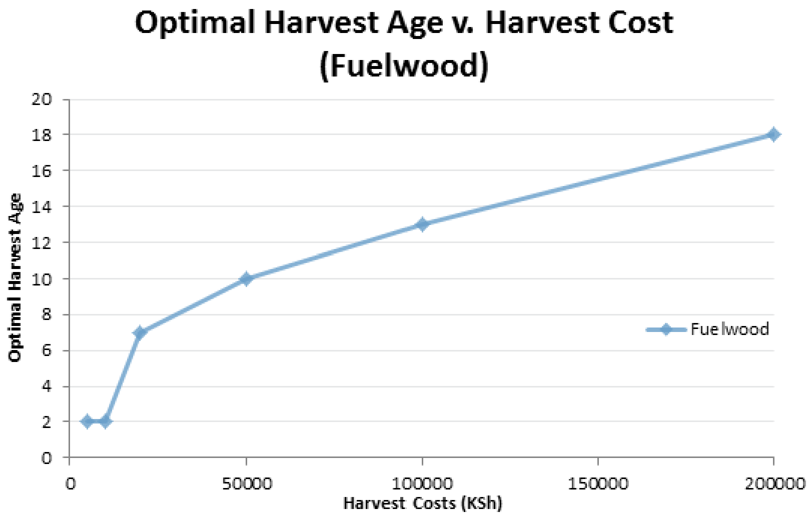
Result:

This analysis shows that under the given scenario, there was a large range for NPV associated with the uncertain harvest cost parameter. This range was expected given the large range in harvest cost values. While maximized total profit declines linearly with increasing harvest cost (graph not shown), maximized NPV declines non-linearly, as shown in GaPP Illustration 1.4.1. The effect on NPV of a marginal change in harvest cost is greater at low values for harvest cost than for high values. This is due to a shift in the optimal harvest age, shown in GaPP Illustration 1.4.2. As harvest cost increases, optimal harvest age also increases. By increasing the harvest age the trees are allowed more time to grow and add value, while simultaneously decreasing the total harvests over the planning horizon and thereby decreasing the associated costs. This also affects the NPV by delaying revenue from the initial harvest, as well as from subsequent harvests. For products whose market prices only depend on a minimum DBH and not volume, for example transmission poles, both maximized total profit and maximized NPV declined linearly with increasing harvest cost (graphs not shown). This is because the optimal harvest age was not affected by the changing harvest costs.

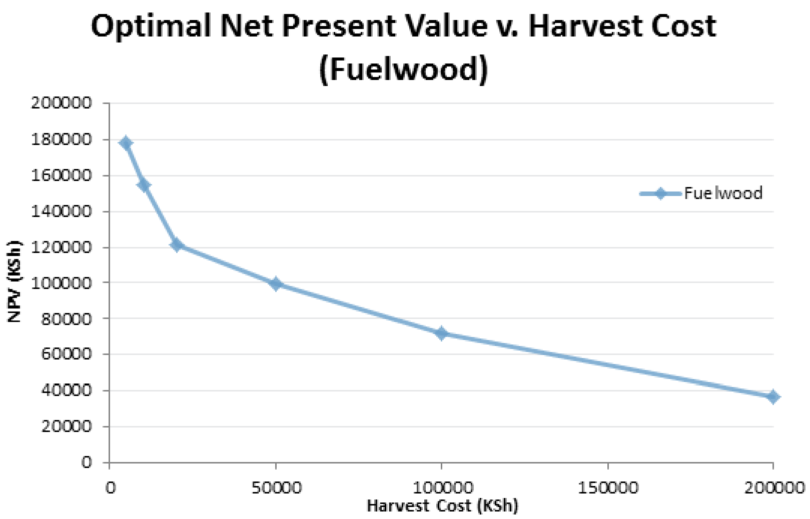
Management Implications:

While this analysis was limited to only one product, either fuelwood or transmission poles, it shows KOMAZA that there can be non-linear relationships between expected NPV and optimal harvest age. From our review of literature and industry articles, the best estimates of harvest cost for fuelwood is between 20,000 KSh per hectare and 35,000 KSh per hectare. If KOMAZA plans for fuelwood production, this analysis would show the likely range for NPV as well as the likely range for optimal harvest age associated with the uncertainty in harvest costs. It also shows that at low values for harvest cost, a marginal decrease in harvest cost yields increasing marginal benefits. While our client is unlikely to optimize its operations for fuelwood production, a similar analysis can be performed using a likely range of harvest costs while including all products. The output of that analysis would inform KOMAZA of the range of likely profits and optimal harvest ages given the uncertainty in this parameter, and help manage expectations for farmers and investors. KOMAZA could also use this type of analysis to consider ways to lower harvest costs, such as purchasing harvest equipment. This knowledge can be used in the third function of the GaPP tool, demonstrated below, to quantify the value or cost of an operational change.

> "...KOMAZA can analyze the max profit and NPV for different treatments under a variety of market price and harvest cost combinations."



GaPP Illustration 1.4.1 Sensitivity of profit to harvest costs by NPV. The effect of harvest cost on net present value (NPV) for fuelwood under a high revenue, medium discount rate (d=0.10), wet climate, FR=0.7 scenario. All other costs were kept at low values. NPV in Kenya shillings is displayed on the Y axis.



GaPP Illustration 1.4.2 Sensitivity of profit to harvest costs by age. The effect of harvest cost on the optimal harvest age for fuelwood under a high revenue, medium discount rate (d=0.10), wet climate, FR=0.7 scenario. All other costs were kept at low values.

Example 1.5

Sensitivity of tree growth and profit to coppicing factor

Sensitivity Analysis

↓

Optimization

↓

Operational Change

↓

Longterm Strategy

Objective:

To determine the effect the coppicing factor has on tree growth and total profit.

Significance:

One of the characteristics that makes Eucalyptus appealing for agroforestry is its natural ability to coppice once harvested, producing new stands without the need to plant new seedlings. In addition, because the root systems are established during the tree's initial growth cycle, subsequent coppices tend to get a boost in growth, reaching greater heights and widths in fewer years. As a result, it is important to examine how the GaPP Tool incorporates this coppicing factor and the effect it has on growth and profit.

Result:

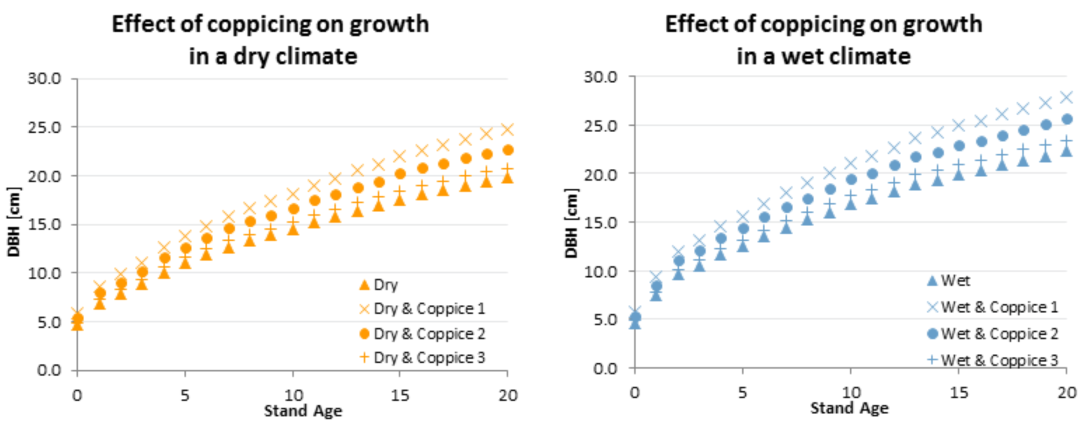
The default coppicing factors currently used by the GaPP Tool are 1.25, 1.15, and 1.05, which represent the 1st, 2nd, and 3rd coppices respectively, and correspond to an initial increase in tree growth of 25% for the 1st coppice and a declining percent increase for the 2nd and 3rd (Cheboiwo & Langat, 2010). Because the coppicing factors are applied to the DBH and stand volume provided by 3PG, the effect on growth is proportional to the coppicing factor, as illustrated in GaPP Illustration 1.5.1. Consistent with the factors, the 1st coppice has the greatest DBH, receiving the largest percentage increase in growth, followed by the 2nd and 3rd coppices, and with the tree's initial growth cycle having the lowest DBH of the four rotation periods.

Next, for a product whose profit is determined by the stand volume, such as fuelwood, the effect of the coppicing factor on profit is the same as growth, yielding the greatest profit in the 2nd rotation period when the stand volume is greatest, followed by the 3rd and 4th rotation periods and with the 1st rotation period generating the lowest profit of the four (see GaPP Illustration 1.5.2). On the other hand, for a product such as transmission poles, whose profit is calculated by tree rather than by volume and requires a minimum DBH before it can be sold on the market as that product, the coppicing factor can have a much more profound effect on profit. As can be seen in GaPP Illustration 1.5.2, in a dry climate, transmission poles are not a profitable product selection in the 1st and 4th rotation periods because they do not reach the minimum DBH required for transmission poles.

In the 2nd and 3rd rotation periods, however, due to the increase in growth provided by the coppicing factors, the stands reach the minimum DBH required for transmission poles and as a result, yield a substantial profit. By contrast, for the wet climate, the coppicing factor has zero effect on total profit because the tree stands already reach the minimum DBH required for transmission poles in the first rotation period and therefore do not receive any extra financial benefit from the boost in growth provided by the coppicing effect.

GaPP Illustration 1.5.1 Sensitivity of tree growth to coppicing factor

The effect of coppicing factor on growth for a dry (left) and wet (right) climate



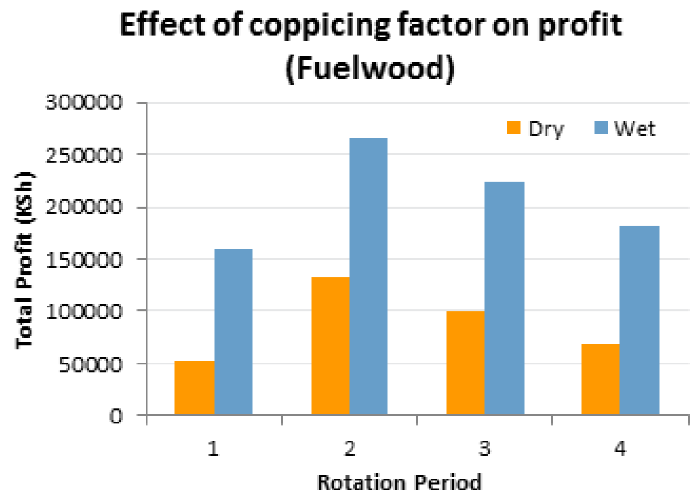
> The additional profitability of coppicing can be profound, but the degree is dependent on the scenario.

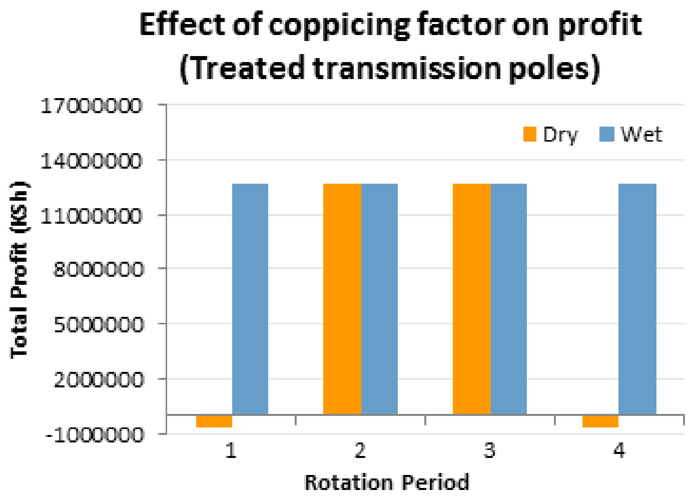
Management Implications:

As demonstrated in GaPP Illustration 1.5.2, coppicing can have a substantial effect on total profit depending on the scenario, due to its influence on growth and consequently, product selection. For this reason, it would be wise for KOMAZA to refine the coppicing factor to its individual sites, possibly through monitoring, so that the GaPP Tool does not overestimate (or underestimate) tree growth in the 2nd, 3rd and 4th rotation periods; such an over- or underestimation could have a huge impact on the optimal harvest age and resulting profit predicted by the tool.

Recommendations:

Our single biggest suggestion would be to collect more accurate information on harvest costs. While conducting the research for this project, we had the most difficulty finding data regarding the costs associated with harvest, including equipment rental, processing, harvest costs for different products, treatment costs for different products, and the cost of logistics for moving the products to certain markets. The inputs we used for these sections were from various sources that ranged from US to Indian markets. Therefore the harvest cost should be assigned a high priority for data collection.





GaPP Illustration 1.5.2 Sensitivity of profit to coppicing factor. The effect of the coppicing factor on total profit when harvesting for fuelwood (left) and for treated transmission poles (right) under both dry and wet climates. A low cost, medium revenue scenario was used and both products were harvested at age 20 for all four rotation periods.

Tool Function 2: Optimization

Optimizing harvest age and product selection to maximize Profit or NPV

Sensitivity Analysis
↓
Optimization
↓
Operational Change
↓
Longterm Strategy

Example 2.1

Determining optimal harvest age to maximize profit or NPV for only one product

Objective:

To determine the optimal profit and harvest age for one product under different cost, revenue and climate scenarios.

Significance:

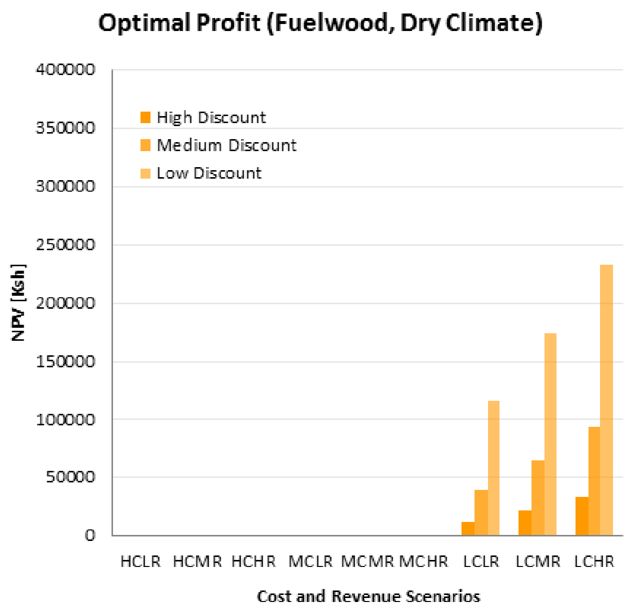
This example introduces the reader to the optimization function of the GaPP Tool by first demonstrating it in a simplified form, optimizing for only one product choice.

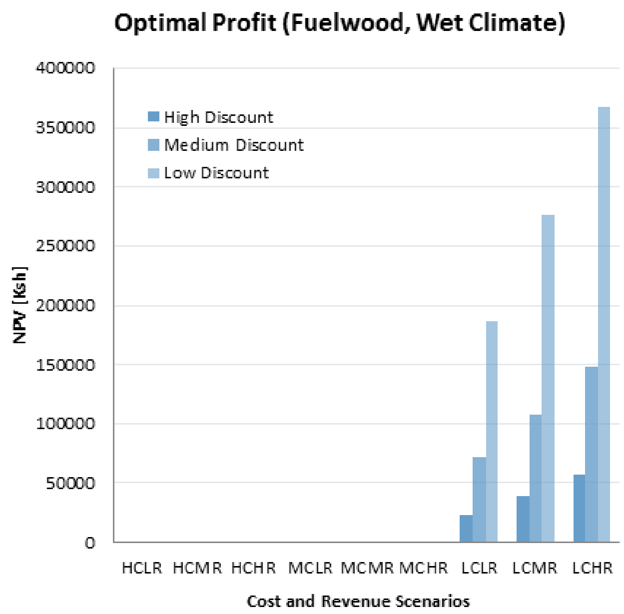
Result:

The maximum NPV for dry and wet climates considered, medium and high costs scenarios produce a positive NPV depending on whether the climate is wet or dry, and which discount rate is most probable. For instance, in the dry climate scenario, the site produces a positive NPV for all cost and revenue combinations when the discount rate is low (see GaPP Illustration 2.2.1). This is because for a low discount rate, the optimal harvest age is 19, at which age the stand reaches the minimum DBH for transmission poles in both the 2nd and 3rd rotation periods, yielding higher total profit and positive NPV.

For medium and high discount rates, however, the harvest age is shifted earlier, to age

GaPP Illustration 2.1.1 Determining maximum NPV for only one product. Maximum NPV for fuelwood for dry (left) and wet (right) climates. Includes all cost and revenue scenarios and discount rates.



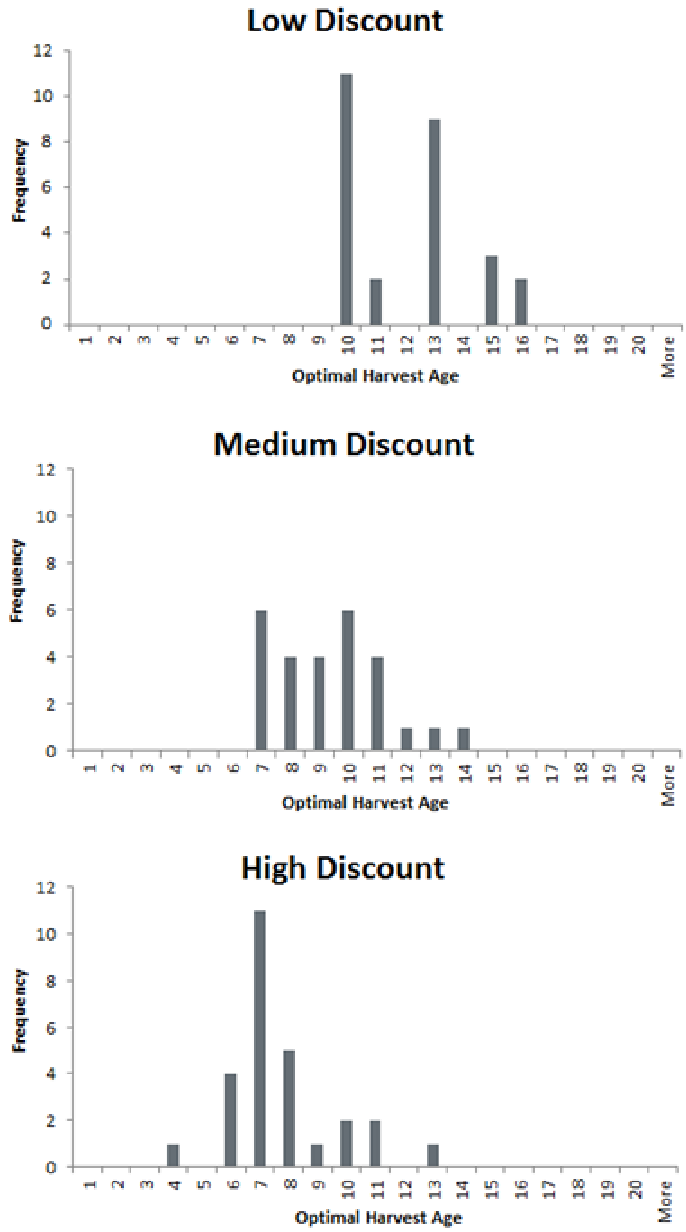


under all cost and revenue scenarios, for all discount rates, and allowing the model to select any of the six products KOMAZA is considering, is displayed in GaPP Illustration 2.2.1. Whereas fuelwood only produced a positive NPV in low cost scenarios (refer to Example 2.1), when all product options are 16 (only yielding transmission poles in the 2nd rotation period) and for some cost and revenue combinations, the optimal harvest age is 2, at which point the model selects roundwood as the most profitable product. In contrast, because the wet climate reaches the minimum DBH for transmission poles at age 20 in the first rotation period and all subsequent rotation periods due to the coppicing factor, the optimal harvest age for the wet climate is always age 20 no matter the cost and revenue scenario.

The discount rate's effect on optimal harvest age when all product choices are considered is demonstrated in more detail in GaPP Illustration 2.2.2. Unlike GaPP Illustration 2.2.1 which features all cost and revenue scenarios for dry and wet climates, GaPP Illustration 2.2.2 shows the optimal harvest age distribution for all low cost scenarios (LCLR, LCMR, LCHR) for all nine soil fertility and climate scenarios. The low cost scenarios were used because every revenue and climate scenario yielded a positive NPV. As can be seen in GaPP Illustration 2.2.2, there is a very distinct bimodal distribution of optimal harvest age. This is due to product selection. For less productive sites, the optimal harvest age is between 1 and 4 years, selecting roundwood or a combination of roundwood and charcoal as the most profitable products. For more productive climates, the optimal harvest age is between age 13 and 20, when transmission poles or a combination of transmission poles and charcoal are the most profitable products. As expected and shown in previous examples, the optimal harvest age is concentrated around earlier ages for higher discount rates.

Management Implications:

This example illustrates how the optimal harvest age and resulting profit and NPV are influenced by a complex suite of variables including discount rate, climate, soil fertility, cost and revenue. Specifically, discount rate can be very deterministic in whether a site produces a positive NPV under certain conditions. For example, in the case of the dry climate featured in GaPP Illustration 2.2.1, the site yielded a positive NPV for a low discount rate under high cost scenarios, but not for a high discount rate. These patterns are important for KOMAZA to recognize as it may affect its strategy with respect to its farmers' discount rates.



GaPP Illustration 2.1.2 Determining optimal harvest age for only one product. Figure 2.1.2: Optimal harvest age distribution for fuelwood based on discount rate. Includes all low cost scenarios (LCLR, LCMR, LCHR) for all nine climate and soil fertility scenarios.

"Optimal harvest age can vary widely as a function of product, discount rate, climate, and site parameters."

Example 2.2

Determining optimal harvest age to maximize profit or NPV for all products

Sensitivity Analysis

Optimization

Operational Change

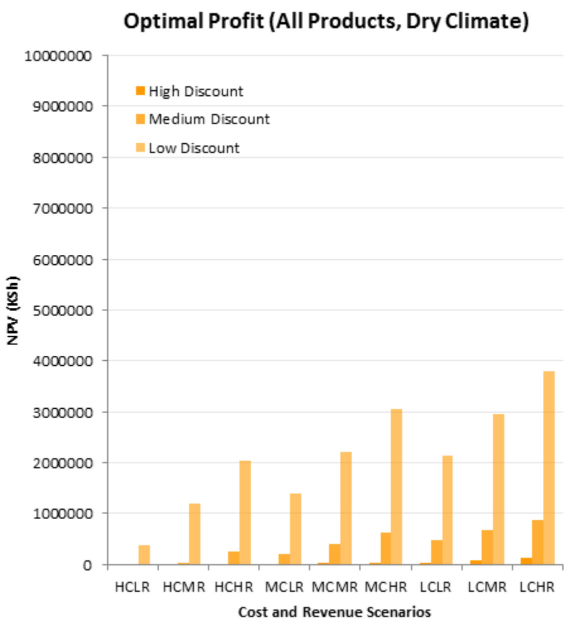
Longterm Strategy

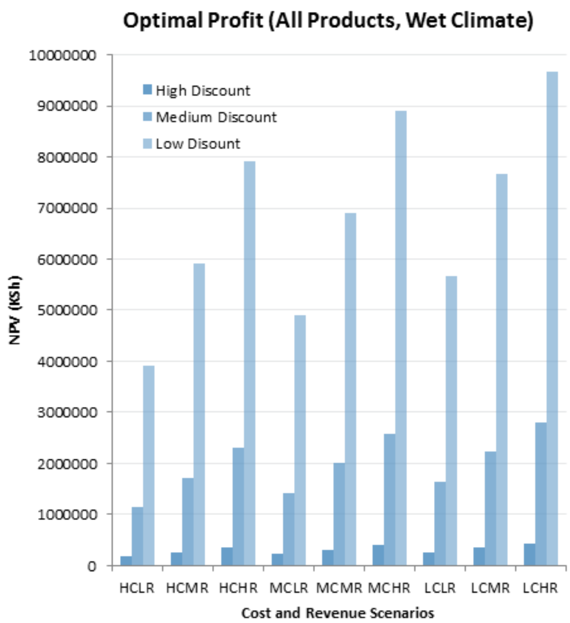
Objective:

To determine the maximum profit and NPV by optimizing harvest age and product selection when considering all possible product choices under different cost, revenue and climate scenarios.

Significance:

The use of the GaPP Tool demonstrated in this example is likely to be one of the most frequent uses of the tool by KOMAZA. By allowing the tool to maximize profit and NPV by optimizing harvest age under multiple scenarios at once while considering all product choices, KOMAZA can both match different scenarios to specific sites, informing site-specific harvest decisions, and also look for patterns that inform broader management decisions.





GaPP Illustration 2.2.1 Determining maximum NPV with all products available for selection. Maximum NPV when considering all products for dry (left) and wet (right) climates. Includes all cost and revenue scenarios and discount rates.

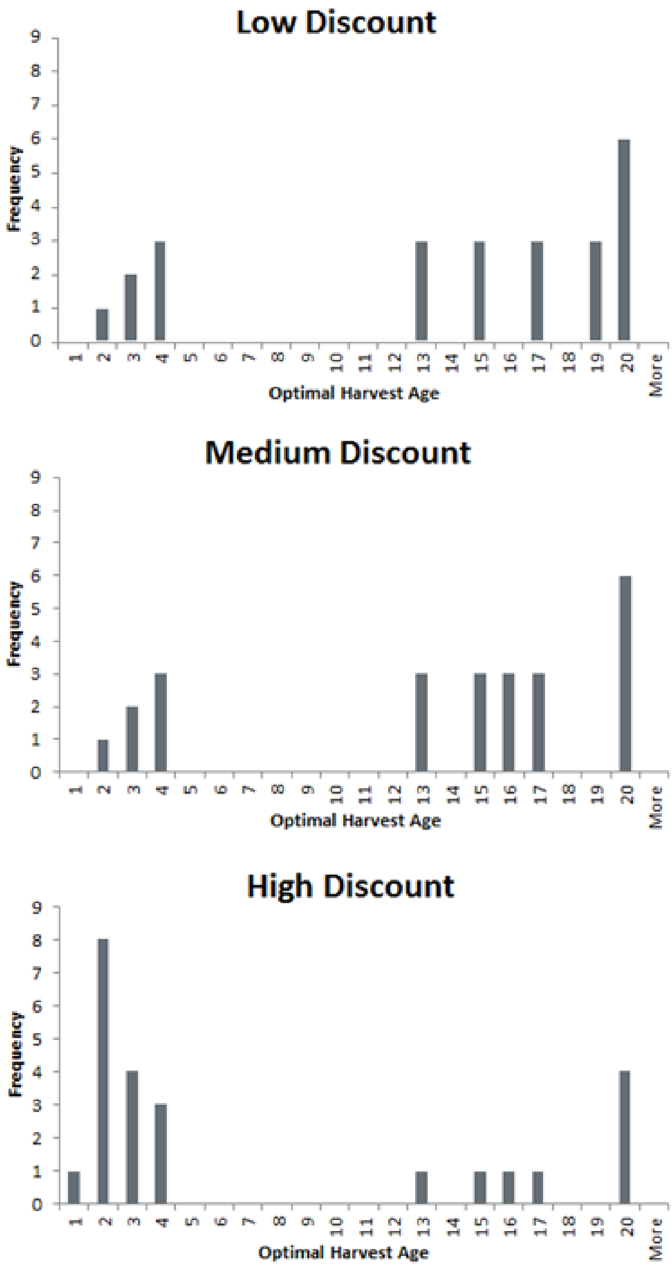
Result:

The maximum NPV for dry and wet climates under all cost and revenue scenarios, for all discount rates, and allowing the model to select any of the six products KOMAZA is considering, is displayed in GaPP Illustration 2.2.1. Whereas fuelwood only produced a positive NPV in low cost scenarios (refer to Example 2.1), when all product options are considered, medium and high costs scenarios produce a positive NPV depending on whether the climate is wet or dry, and which discount rate is most probable. For instance, in the dry climate scenario, the site produces a positive NPV for all cost and revenue combinations when the discount rate is low (see GaPP Illustration 2.2.1). This is because for a low discount rate, the optimal harvest age is 19, at which age the stand reaches the minimum DBH for transmission poles in both the 2nd and 3rd rotation periods, yielding higher total profit and positive NPV. For medium and high discount rates, however, the harvest age is shifted earlier, to age 16 (only yielding transmission poles in the 2nd rotation period) and for some cost and revenue combinations, the optimal harvest age is 2, at which point the model selects roundwood as the most profitable product. In contrast, because the wet climate reaches the minimum DBH for transmission poles at age 20 in the first rotation period and all subsequent rotation periods due to the coppicing factor, the optimal harvest age for the wet climate is always age 20 no matter the cost and revenue scenario.

The discount rate's effect on optimal harvest age when all product choices are considered is demonstrated in more detail in GaPP Illustration 2.2.2. Unlike GaPP Illustration 2.2.1 which features all cost and revenue scenarios for dry and wet climates, GaPP Illustration 2.2.2 shows the optimal harvest age distribution for all low cost scenarios (LCLR, LCMR, LCHR) for all nine soil fertility and climate scenarios. The low cost scenarios were used because every revenue and climate scenario yielded a positive NPV. As can be seen in GaPP Illustration 2.2.2, there is a very distinct bimodal distribution of optimal harvest age. This is due to product selection. For less productive sites, the optimal harvest age is between 1 and 4 years, selecting roundwood or a combination of roundwood and charcoal as the most profitable products. For more productive climates, the optimal harvest age is between age 13 and 20, when transmission poles or a combination of transmission poles and charcoal are the most profitable products. As expected and shown in previous examples, the optimal harvest age is concentrated around earlier ages for higher discount rates.

Management Implications:

This example illustrates how the optimal harvest age and resulting profit and NPV are influenced by a complex suite of variables including discount rate, climate, soil fertility, cost and revenue. Specifically, discount rate can be very deterministic in whether a site produces a positive NPV under certain conditions. For example, in the case of the dry climate featured in GaPP Illustration 2.2.1, the site yielded a positive NPV for a low discount rate under high cost scenarios, but not for a high discount rate. These patterns are important for KOMAZA to recognize as it may affect their strategy with respect to their farmers' discount rates.



GaPP Illustration 2.2.2 Determining optimal harvest age with all products available for selectionOptimal harvest age distribution when considering all products based on discount rate. Includes all low cost scenarios (LCLR, LCMR, LCHR) for all nine climate and soil fertility scenarios.

> "Determining optimal harvest age is likely to be one of the most frequently used Tool Functions for KOMAZA."

Example 2.3

Expected optimal harvest age and product selection given uncertainty in parameter values

Sensitivity Analysis

↓

Optimization

↓

Operational Change

↓

Longterm Strategy

Objective:

To determine the optimal harvest age and product selection to maximize expected profit and NPV if parameter values are uncertain. The following analysis can be performed if there are two or more possible values for uncertain parameters. If the probability that one parameter value is the actual value that probability can be used to weight the output of the GaPP tool to predict the expected optimal harvest age and expected maximum profit.

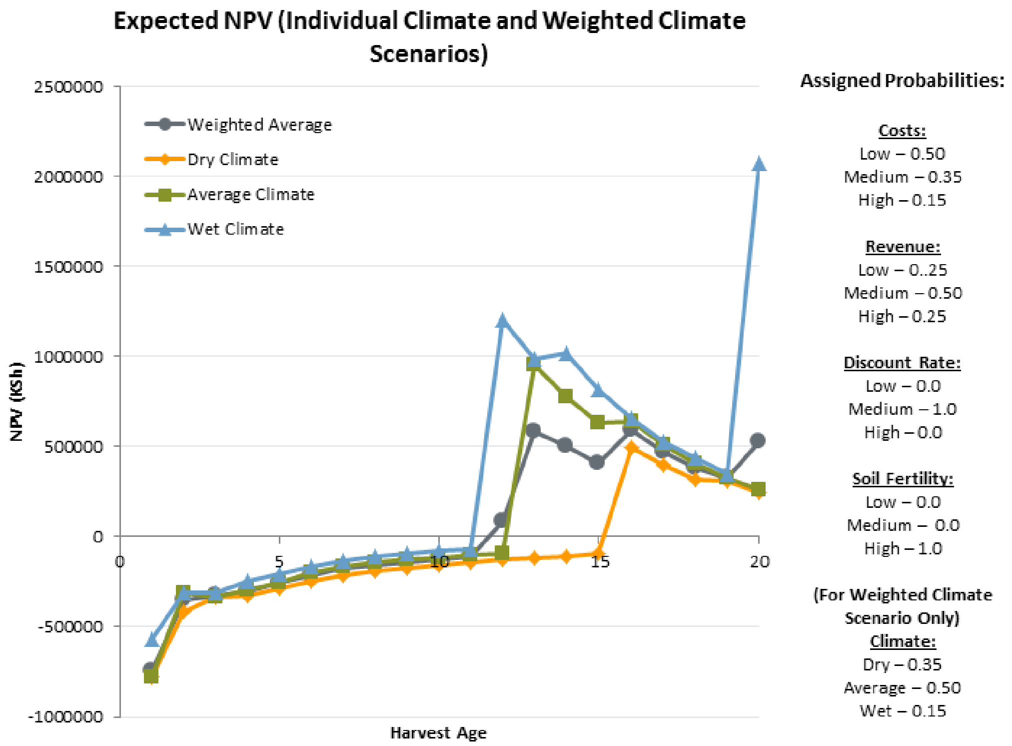
Significance:

Uncertainty in parameter values can result in a wide range of possible optimal harvest ages (shown in GaPP illustration 2.2.2) complicating KOMAZA's ability to make the best management decisions. However, if KOMAZA knows the probability that a particular parameter value is correct, that probability can be used to weight the GaPP tool output to determine the expected optimal harvest age and expected maximum profit. This allows KOMAZA to recommend one optimal harvest age to their farmers that is most likely to maximize profit and NPV.

Result:

The results from Example 2.2, which determined the optimal harvest age and associated profit for different cost, revenue, and climate scenarios were used in this analysis. For the purpose of demonstrating this tool function, a weight was assigned to the parameter values listed below based on our best guess of that value's probability of being the actual value. While the probabilities used in this demonstration were assigned subjectively, KOMAZA can use their knowledge to assign probabilities of occurrence to each parameter value, given a range of possible values. The probabilities/weights used in this demonstration were: low cost = 0.50, medium cost = 0.35, high cost = 0.15, low revenue = 0.25, medium revenue = 0.50, high revenue = 0.25. For this example a high soil fertility and medium discount rate were assumed. The weights above were multiplied to weight each cost and revenue combination. This weight was then multiplied by the profit and NPV (d=0.10) results from Example 2.2 and summed to get an expected profit and NPV for each climate scenario shown in GaPP Illustration 2.3. Weights were then assigned to each climate scenario given its probability of occurrence at a particular site: dry (S3C1V2) = 0.35, average (S3C2V2) = 0.50, wet (S3C3V2) = 0.15. These weights were multiplied by the expected profit and NPV calculated in the previous step and summed to get a weighted average, shown in GaPP Illustration 2.3. As expected, the average is between the high and low expected NPV, tracking the average climate most closely since it was the most heavily weighted climate. In this demonstration, the expected optimal harvest age for the dry climate was 16 years, the expected optimal harvest age for the average climate was 13 years, the expected optimal harvest age for the wet climate was 20 years, and the expected opti-

> "If probabilities of different cost, revenue, and climate scenarios are known, a single optimal harvest period can be determined."



GaPP Illustration 2.3 Determining expected NPV given probabilities of different scenarios.

Expected NPV (d=0.1) for dry (S3C1V2), average (S3C2V2), and wet (S3C3V2) climates using weighted average for all cost and revenue combinations. The expected NPV for all climates in shown as "weighted average".

mal harvest age for all climate scenarios was 16 years, shown in GaPP Illustration 2.3.

Management Implications:

Example 2.2 illustrates how our client can find the optimal harvest age and associated profit and NPV for combinations of uncertain parameter values. However, GaPP Illustration 2.2.2 shows that uncertainty in parameter values can lead to a large range of possible optimal harvest ages. While the utility of this analysis is discussed above, KOMAZA may want to recommend a single optimal harvest age to their farmers. In order to make the best possible management decision given this uncertainty, another type of analysis is needed. For instance, if KOMAZA has some knowledge about the probability of occurrence for each cost-price-climate scenario for a specific site, the analysis in this example can be performed. Another application of this analysis would be if KOMAZA wants to recommend one harvest age to multiple farmers, despite different site-specific characteristics that will lead to different optimal harvest ages. If those site-specific parameter values are certain, the proportion of farms included in the analysis with that particular parameter value could be used to weight the outcome. The analysis in this example will aid KOMAZA in making management decisions regarding its optimal harvest period given uncertain parameter values, if the probabilities of different cost, revenue, and/or climate scenarios are known. This will also aid the organization in managing expectations for their farmers and donors.

Tool Function 3: Value of Operational Changes

Calculating expected value of changes to operational

Example 3.1

Value of travelling farther to reach a more profitable market

Sensitivity Analysis

↓

Optimization

↓

Operational Change

↓

Longterm Strategy

Objective:

To calculate the tradeoffs associated with travelling to a market that is farther away but more profitable.

Significance:

This demonstrates how KOMAZA will be able to use this tool function to calculate the value, or expected value of a specific operational change.

Result:

In this example, the results from example 2.2 were used to model the value of a specific operational change, investing in travel to a more profitable market. Building on the functionality of the GaPP tool and for a clearer demonstration of this function, it was assumed that initial model parameters were certain. Default parameters were used, with a wet climate. To better show the effect of this change, it was assumed that treated transmission poles were not an option and that untreated transmission poles were the selected product. To model the operational change of accessing a more profitable market, the market price for untreated transmissions poles was increased from the default price of 1350KSh per pole to 1400KSh per pole. In addition, to simulate a market that is farther from Ganze District, transportation and labor costs were added to the default harvest cost. Six values were used for the additional transportation costs, ranging from 5000KSh to 80,000KSh. For the first analysis, it was assumed that the values for additional transportation costs were certain, and can be viewed as simulating six different markets. Given these new parameter values, the GaPP tool was used to optimize the operations under the proposed operational change. GaPP Illustration 3.1.1, shows the NPV from the current operations (shown as the orange bars) compared to the expected NPV under the operational change (shown as the green bars). The expected value of the operational change is calculated as the difference between the NPV under the proposed change and the NPV under the current operations. GaPP Illustration 3.1.1 shows that accessing a more profitable market that is close to Ganze District, represented by a small increase in transportation costs, can yield large increases in NPV, while accessing markets that are far away may result in a cost to the organization.

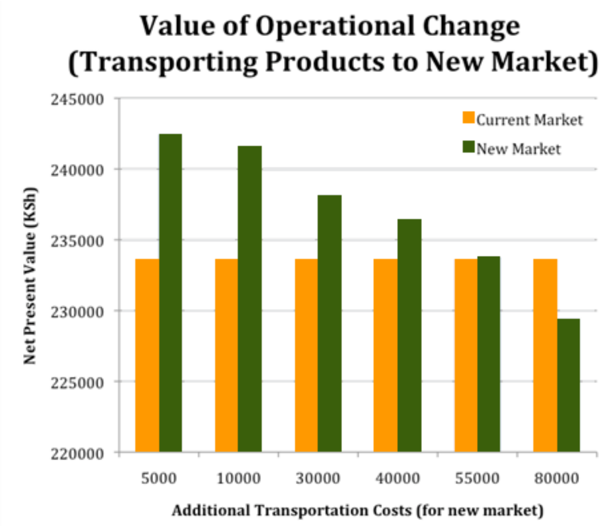
Next, the expected value of this operational change was calculated under parameter uncertainty. The same values were used for additional transportation costs in this analysis, but

> "An operational change may have a high probability of adding value, with a low probability of being costly."

were now assumed to represent one potential new market, with a certain market price but a large degree of uncertainty for harvest cost. For this demonstration it was assumed that the cost of transportation to this hypothetical market was uncertain and each value for transportation costs, used above, was equally probable. GaPP Illustration 3.1.2 shows a boxplot of the expected NPV under the operational change given the stated parameter uncertainty. The orange dot shows the expected NPV under the current operations. Both the median and the interquartile range have higher NPV than the NPV under the current operations. However, the lower tail of the boxplot shows that for one scenario, if transportation costs are very high, NPV will decrease. Since it was assumed that each value for harvest cost was equally likely, the expected NPV associated with this operational change is represented by the mean. If some uncertain parameter values were more likely than others, and if their relative probabilities of being the actual value were known, the outcomes could be weighted based on those probabilities and the weighted mean would represent the expected value of the operational change.

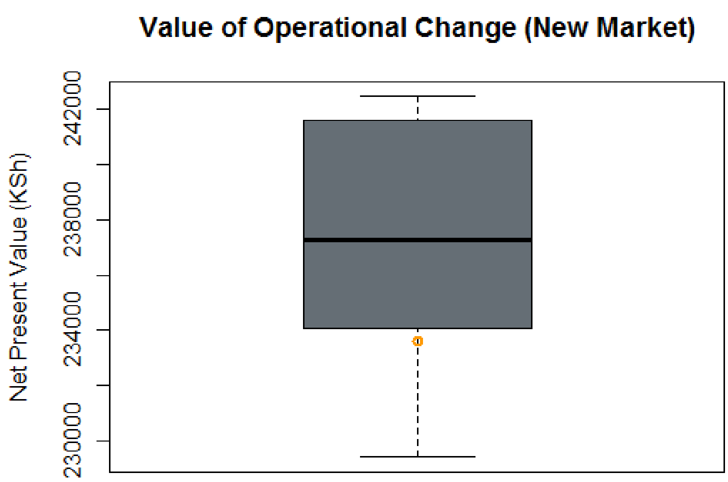
Management Implications:

This example shows that if parameter values are certain, the calculation of the value of an operational change is straightforward. If this is the case, KOMAZA can use the GaPP tool to model operational changes and implement the changes that yield the most value to the organization and its farmers. This example also outlines the method to calculate the value of an operational change given parameter value uncertainty and if relative probabilities for those values are known. As shown in illustration 3.1.2, an operational change may have a high probability of adding value, while there may be a small probability that it is very costly. The decision regarding whether the proposed operational change should be made will depend on the decision-makers and their level of risk-averseness. This decision will depend on the probability that the change will increase the NPV and by how much, versus the probability that it decreases it and by how much. While the GaPP tool does not prescribe a decision, it can help KOMAZA make a more informed decision whether to make a change in their operations



GaPP Illustration 3.1.1 Bar graphs of NPV under current operations and an operational change. Comparison of expected NPV using a current market (orange) and a new market (green). The difference in NPV between green and orange bars represents the value of the operational change, given additional market price and harvest cost as specified. This illustration assumes parameter certainty. Unless noted, default parameter values were used, with a wet climate.

GaPP Illustration 3.1.2 Boxplot of expected NPV under an operational change if parameter values are uncertain. This boxplot shows NPV under an operational change (accessing a new market), with uncertain transportation and labor costs, given equal probabilities that each uncertain parameter value is the actual value. The black line is the median value, the box is the interquartile range, the tails are the range of values and the orange dot is the NPV under the current operations.



Example 3.2

Value of increasing or decreasing fertilizer use at different stages of tree growth

Sensitivity Analysis

↓

Optimization

↓

Operational Change

↓

Longterm Strategy

Objective:

To determine if increasing or decreasing fertilizer use at various stages of the tree's growth increases profitability of a site.

Significance:

Example 1.1 indicated that soil fertility had a significant effect on tree growth, and as a result, suggests that KOMAZA, to the extent possible, will want to adjust their fertilizer application rates in order to maximize tree growth. This example seeks to provide further insight on how best to vary fertilizer use to maximize profitability by modeling scenarios with higher soil fertility in the first years of stand growth and decreasing fertility at later stages of stand growth. This will also aid KOMAZA in analyzing potential trade-offs between profitability and environmental impacts associated with fertilizer use.

Result:

In addition to the default scenario, S3, in which the soil fertility rating stays constant at 0.7 during the entire 20 years of stand growth, five other scenarios were modeled in this example, denoted by S4 to S8. The S4 and S5 scenarios start with higher initial soil fertility with decreasing soil fertility later in the growth cycle. Specifically, S4 starts with a fertility rating of 0.8, decreasing to 0.7 after the first seven years and decreasing to 0.6 at age 14. Similarly, S5 starts with a fertility rating of 0.9, decreasing by one-tenth steps every 4 years, resulting in a final fertility rating of 0.5. Unlike the S4 and S5 scenarios, S6, S7, and S8 only model a decrease in soil fertility, thereby decreasing soil fertility from 0.7 to 0.5 at ages 14, 12, and 10 respectively. Furthermore, costs were not varied during this analysis. While changing fertilizer application rates would in reality change KOMAZA's annual costs, it was found that for the low cost scenario, fertilizer costs did not have a significant impact on overall profitability of the site; the difference between including fertilizer costs (1575 KSh/year) versus not including any fertilizer costs (0 KSh/year) did not change the optimal harvest age selected by the model and only changed the maximum NPV by up to 1%. Therefore, changing the fertilizer costs subtly over time to reflect varying fertilizer application rates would have an even smaller effect and consequently, was excluded from this analysis.

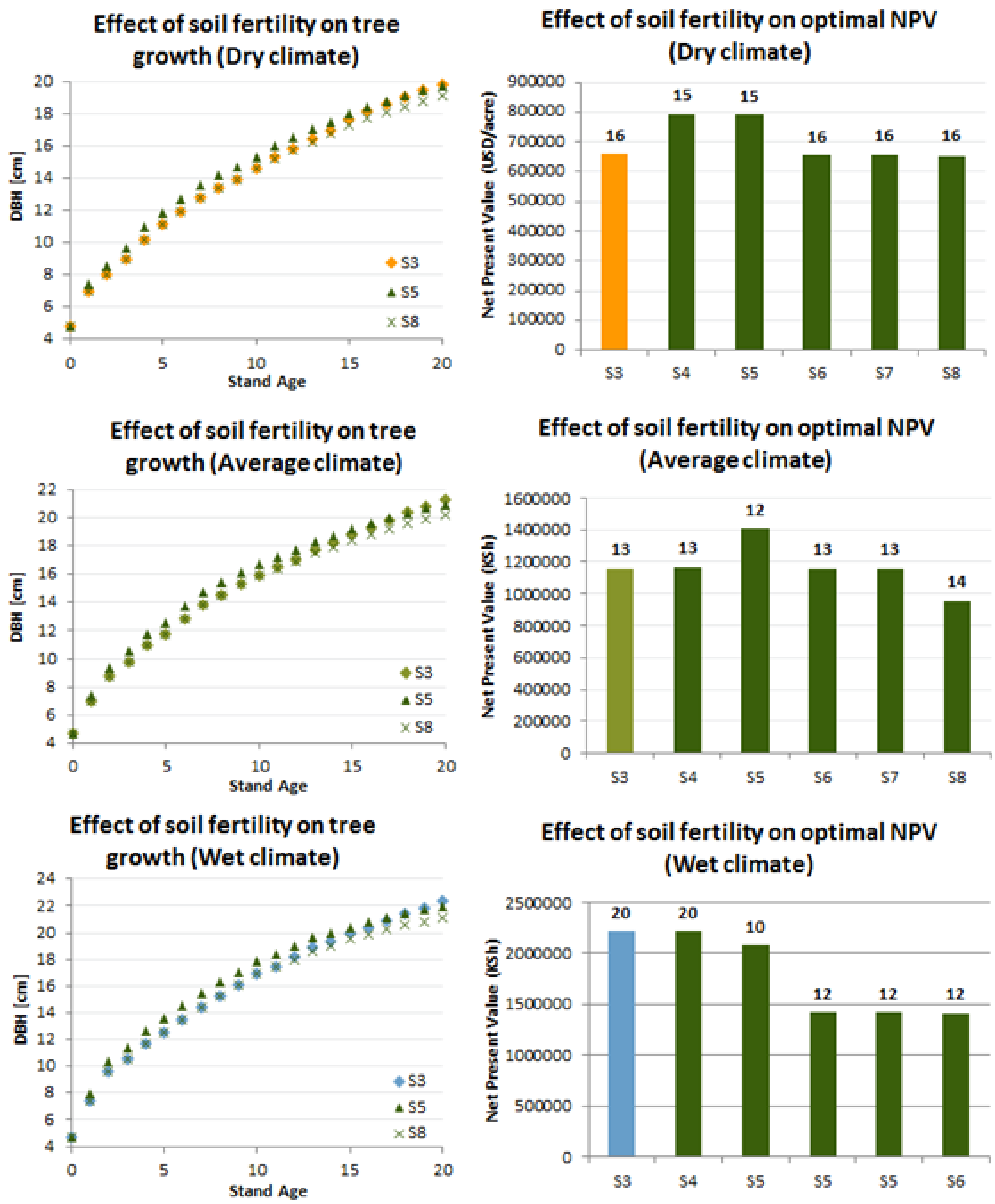
The results from this example are displayed in Figure 3.2. While the effect of fertilizer use on tree growth may appear insignificant, depending on the climate and soil fertility scenario, it can have a substantial effect on maximum profit when it results in an earlier optimal harvest age (as seen in Figure 3.1). For example, in the case of a dry climate, the early boost in tree growth provided by higher initial soil fertility ratings results in a decrease in optimal harvest age from 16 (S3) to 15 (S4, S5), eliminating an additional year of annual costs. This is because the minimum DBH for the highest value product, transmission poles, is reached at age 15.

> "Altering fertilizer applications rates at levels high enough to alter a site's soil fertility can significantly change the profitability of a site."

In addition, for the dry climate, decreasing fertilizer use later in the tree's growth cycle does not have a significant impact on maximum profit (less than 1%) because there is no change in optimal harvest age. By contrast, for the wet climate, decreasing the fertilizer use later in the tree's growth cycle does substantially affect the optimal harvest age and profit due to product selection; for S5, S6, S7, and S8 scenarios, the tree's DBH at age 20 does not reach the 22 centimeters needed to harvest for transmission poles, leading to reduced profit.

Management Implications:

As shown in Figure 3.2, altering fertilizer application rates at levels high enough to alter a site's soil fertility rating can significantly change the profitability of a site, both positively and negatively. This change, however, is dependent on multiple inputs, particularly climate and product selection. For this reason, varying fertilizer application rates, which directly impacts soil fertility, a site-specific parameter, is an operational change that KOMAZA would have to evaluate on a site-by-site basis. Additionally, while this is only an example, it can inform important management decisions. Under a dry climate, if KOMAZA's sole goal is poverty alleviation, and therefore maximization of NPV, the organization would choose to use additional fertilizer at early stand ages and decline fertilizer use at later stages, similar to the S4 and S5 scenarios. However, this additional fertilizer use may have adverse effects on environmental quality, such as eutrophication of waterways. If KOMAZA wants to also consider their environmental impacts, all negative (and positive) effects of their operations should be taken into account when making management decisions. If this is the case, KOMAZA could opt to decrease fertilizer use later in the stand age, similar to scenarios S6, S7, and S8. Since these operational changes have a negligible effect on profitability, they could potentially improve environmental quality and help KOMAZA attain their goal of environmental sustainability while minimizing losses to profitability. In this way, function three of the GaPP tool can aid KOMAZA in analyzing trade-offs between profitability and environmental sustainability. Additional recommendations for addressing and mitigating environmental impacts are included in the Recommendations section of this report. It is also important to note that while growth may be affected only slightly by altering fertilizer application, there may be threshold effects that substantially decrease profitability, as seen in scenarios S5, S6, S7, and S8 for a wet climate. This reinforces the need for KOMAZA to use the GaPP tool on a site-by-site basis to make the most informed management decisions



GaPP Illustration 3.2 1 Effect of varying soil fertility on tree growth and profitThe effect of fertilizer use on tree growth (left) and optimal NPV (right) for dry, average and wet climates with the default soil fertility scenario, S3, shown in orange, light green or blue depending on the climate while the new soil fertility scenarios are shown in dark green. In addition, the optimal harvest age is shown above the corresponding profit bars. The NPV calculated in this example uses low cost, medium revenue, medium discount rate and optimizes over all product choices.

Example 3.3

Comparative analysis of maximum profit for treated poles versus untreated poles

Sensitivity Analysis

↓

Optimization

↓

Operational Change

↓

Longterm Strategy

Objective:

To compare maximum profit and NPV for treated and untreated transmission poles for different market prices and harvest costs.

Significance:

This type of analysis shows which product will be more profitable for different combinations of market price and harvest cost, if other parameter values are certain.

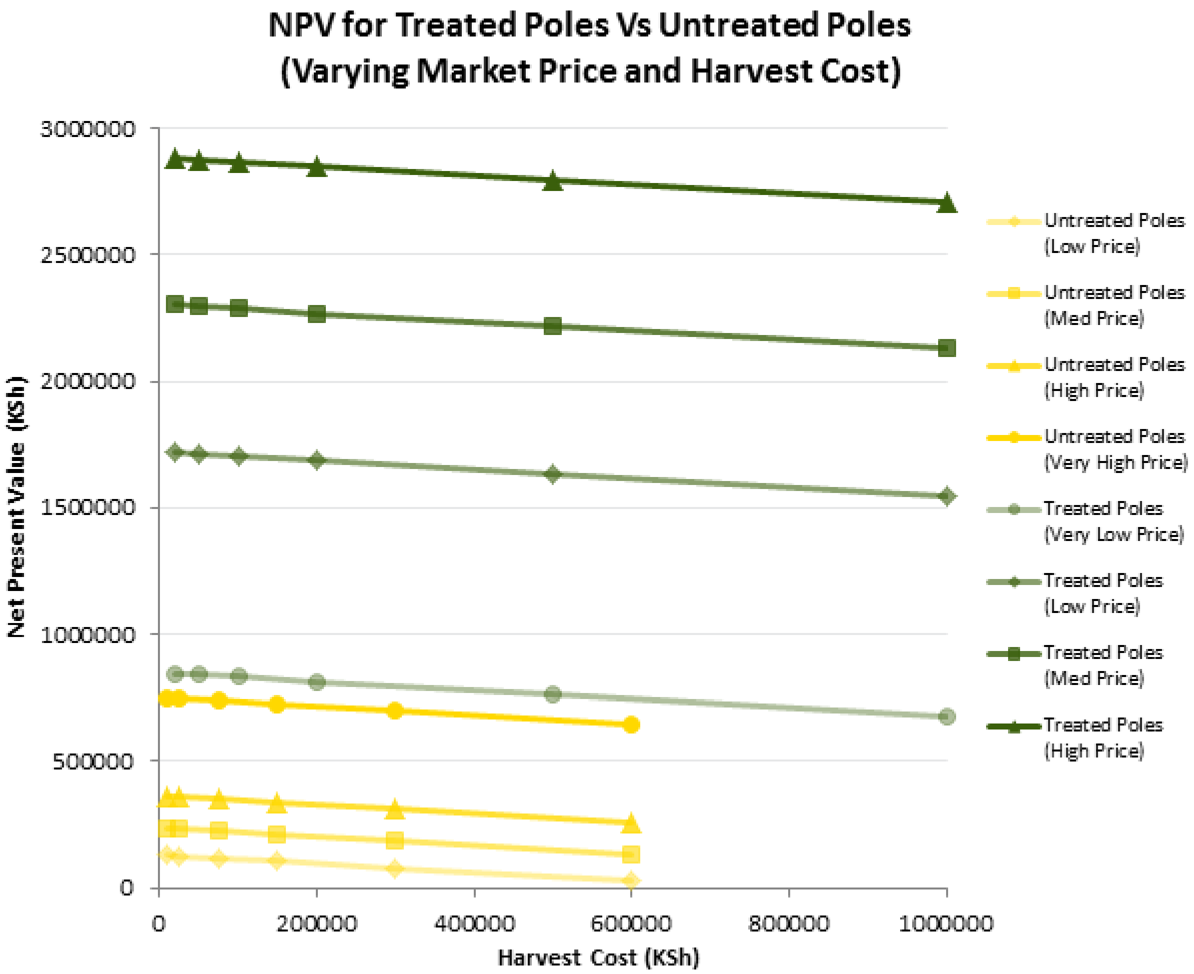
Result:

The GaPP tool was used to find the maximum profit and NPV assuming a wet climate and a medium discount rate for treated or untreated transmission poles, while varying the harvest cost and market price. Initial and annual costs were assumed to be low. For untreated poles, the harvest cost was varied between 10,000KSh and 600,000 KSh. Since treated transmission poles require additional processing and treatment costs, harvest cost values were varied between 20,000KSh and 1,000,000KSh. Default high, medium, and low market prices were used for each product. These are shown in GaPP Illustration 3.2.1 as the top three lines for treated poles and the bottom three lines for untreated poles. For these market prices and harvest costs, treated transmission poles will always have a higher profit and NPV. If the market price for untreated transmission poles is double the high default value and if the market price for treated transmission poles is half the low default values, the most profitable product then depends also on harvest cost.

Management Implications:

If KOMAZA selects a product, such as transmission poles, it may have an additional choice regarding whether to further treat or process the product to add value. The analysis shown in this example will allow our client to analyze the maximum profit and NPV for different treatment options under a variety of market price and harvest cost combinations. The results of this example, shown in GaPP Illustration 3.2.1, suggest that only in a market with a price for untreated poles that is double the highest price found in the literature and a price for treated poles that is half the lowest price found in the literature will untreated poles be more profitable (and only under certain harvest cost combinations (Cheboiwo, 2009). If KOMAZA runs a similar analysis it can determine which product treatment will be most profitable, given likely combinations of market price and harvest cost. Once a product treatment has been selected, KOMAZA can then focus on operational changes that can lower the harvest cost, such as purchasing equipment rather than renting it, or increasing the market value by transporting products to more profitable markets. This analysis can be performed for any product with separate processing options.

> "...KOMAZA can analyze the max profit and NPV for different treatments under a variety of market price and harvest cost combinations."



GaPP Illustration 3.2 Optimal profit for treated poles versus untreated poles. Optimal NPV (d=0.10) in a wet climate for treated and untreated transmission poles, varying harvest cost and market price.

Tool Function 4: Long-term Strategy

Evaluating possible effects of climate change on growth and profit

Sensitivity Analysis

↓

Optimization

↓

Operational Change

↓

Longterm Strategy

Example 4.1

Evaluating possible effects of climate change on growth and profit

Objective:

To investigate the potential impacts of climate change on tree growth and profit in order to inform future management strategies in adapting to climate change.

Significance:

For KOMAZA's business to be sustainable in the long-term, KOMAZA will need to be able to adapt to climate change. Although it is uncertain what form climate change will take in the region, the GaPP Tool can be used to model potential climate change scenarios to provide a preliminary look at how climate change will affect KOMAZA's farms and general operations.

631 mm

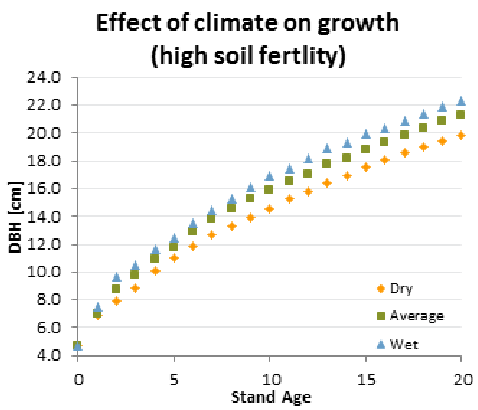
Average annual rainfall during a dry year. Growth rates are predicted to be 20 cm at year 20.

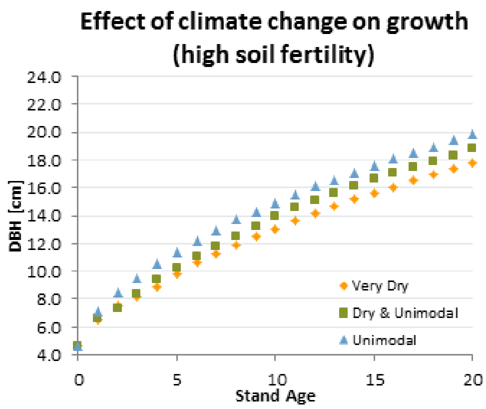
956 mm

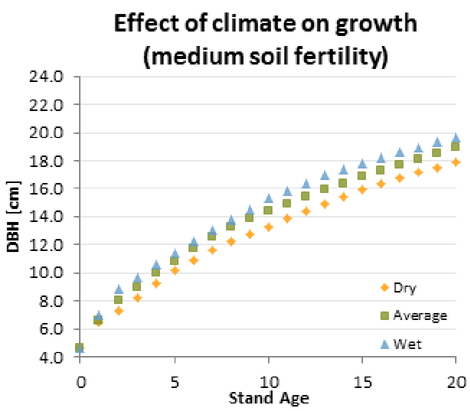
Average annual rainfall during a unimodal year. Growth rates are still predicted to be 20 cm at year 20.

Result:

Three climate change scenarios were modeled in this analysis: a very dry climate (CC1), a unimodal precipitation distribution, where there is only one annual rainy season instead of two distributed throughout the year (CC2), and a dry climate with a unimodal precipitation distribution (CC3). The first, an extremely dry climate, was chosen because we found that Mombasa had experienced seven of the driest years on record in the 2000s. We also simulated a switch to a unimodal precipitation pattern, because some Global Climate Models have predicted a switch to unimodal rains for the region (Dinar, Benhin, Hassan, & Mendelsohn, 2012). The very dry climate is composed of years whose total annual precipitation values are in the bottom 2% of the precipitation dataset. The unimodal climate is made from years with both high seasonality (i.e. 77-84% of the precipitation occurs during the rainy seasons) and high modality (i.e. 76-90% of the rains that fall during the rainy season occur dur-







GaPP Illustration 4.1.1 Evaluating possible effects of climate change on growth

The effect of climate change on tree growth given a soil fertility rating of 0.7 (top) compared with Example 1.1's sensitivity analysis of tree growth to climate for soil fertility ratings of 0.7 (3rd) and 0.5 (bottom).

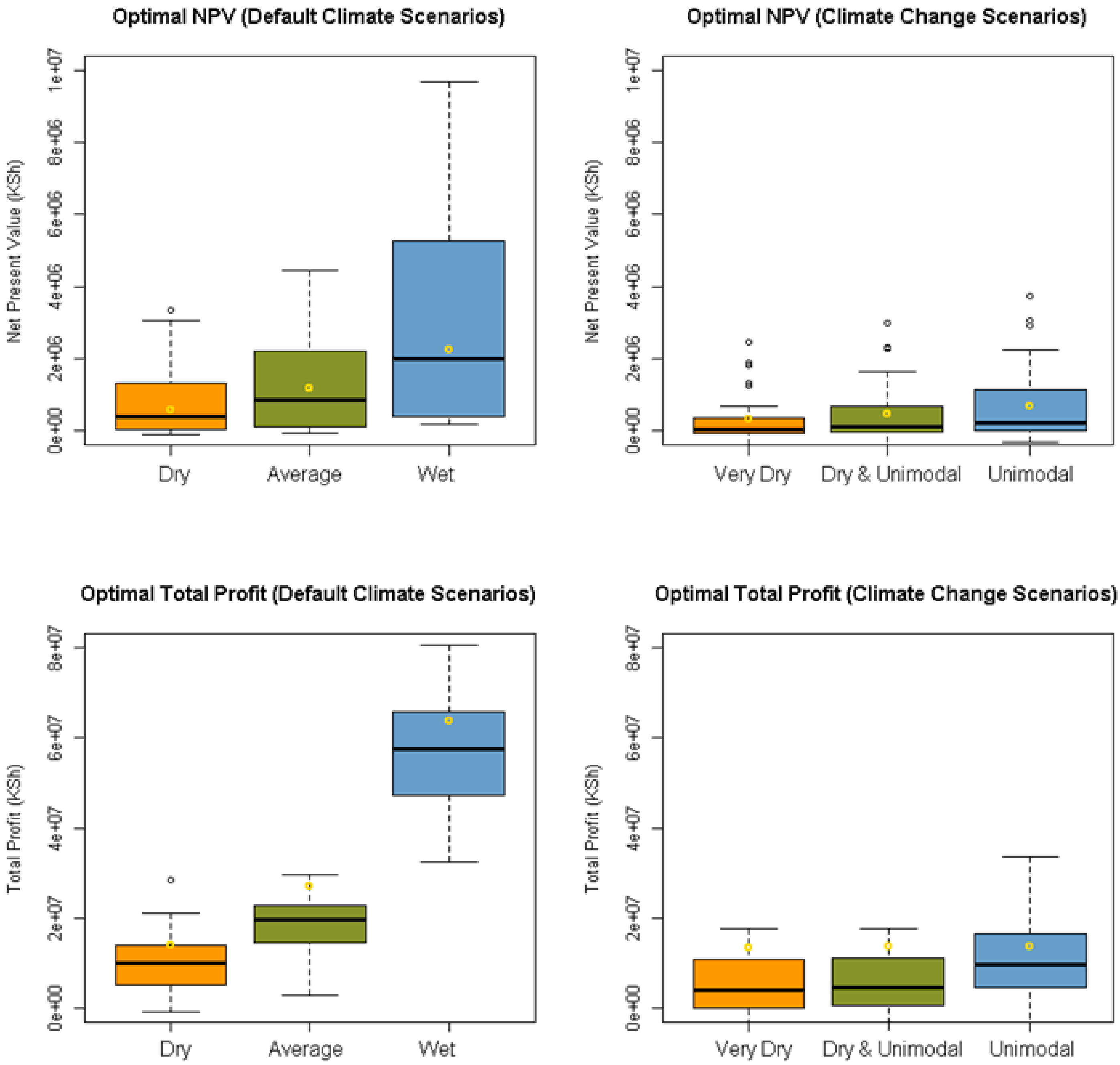
ing only one of the rainy seasons); these years were all "average" or "wet" years. Finally, the dry and unimodal climate consists of "dry" years with high seasonality (70-76%) and high modality (70-82%). The effect of these three climate change scenarios on tree growth is displayed in GaPP Illustration 4.1.1.

Not surprisingly, the very dry climate, which averages 457 mm of precipitation a year, is the least productive climate, producing stands with a DBH of 17.8 cm at age 20, 2 cm lower than the DBH at age 20 for our default dry climate scenario. What is particularly interesting, however, is that the unimodal climate, which averages 956 mm of precipitation a year, produces the same DBH at age 20 as the default dry climate, which only averages 630 mm of precipitation a year. This result indicates that tree growth is not only dependent on total annual precipitation but the distribution of precipitation throughout the year. Also interesting to note, the resulting tree growth under climate change for a site with our default soil fertility rating of 0.7 is extremely similar to the tree growth for a site with a soil fertility rating of 0.5 for our default dry, average and wet climates (see GaPP Illustration 4.1.1).

The effect of these climate change scenarios on both maximum total profit and NPV was also investigated and shown in GaPP Illustration 4.1.2. In addition to the boxplots showcasing the range of profit for each climate scenario (given all combinations of cost, revenue and discount rate) yellow points are also plotted in GaPP Illustration 4.1.2 to indicate where the low cost, medium revenue and medium discount rate scenario (considered our best guess at parameter values) falls within that range. Consistent with the growth results, the CC2 scenario is most comparable to the dry climate in terms of total profit while the CC1 and CC3 scenarios are less profitable overall. When comparing all the scenarios' NPVs, however, all climate change scenarios' interquartile ranges and median NPVs are lower than that of the dry climate. In addition, the climate change scenarios have higher incidence of negative total profit and negative NPV than the default climates and some of the higher NPV points for the climate change scenarios are considered outliers.

Management Implications:

As KOMAZA crafts long-term management strategies, it is important that it consider the impacts of climate change on its farms and operations, and create a plan to adapt to these impacts. As the preliminary results from this example demonstrate, sites could average 2 cm less growth per tree under climate change conditions compared to the present climate, and as a result, yield lower profits. The results also indicate that this decrease in productivity may be comparable to a decrease in soil fertility rating from 0.7 to 0.5 under current climate conditions. While preliminary, this outcome offers two important insights: (1) with climate change, even KOMAZA's most fertile sites may see profits comparable to today's less fertile sites, and (2) KOMAZA can use today's less fertile sites to inform best management practices and prepare for similar conditions in the future. The outcomes of this type of analysis can help KOMAZA scale up its operations in a sustainable way, by adding new sites that are most likely to remain profitable under climate change scenarios. Since KOMAZA's primary goal is poverty alleviation, they may still choose to scale up to sites with low productivity. However these sites may need to be offset with more productive sites to maintain long-term financial sustainability. An additional concern is how climate change will affect global markets for wood products. While KOMAZA will be selling products to local markets that will likely be insulated from changes in the global market, the possibility of declining market prices due to increased global productivity should be incorporated into its long-term strategic planning.



GaPP Illustration 4.1.2 Evaluating possible effects of climate change on profit. Optimal NPV and total profit for the default climate scenarios (dry, average, wet, FR=0.7) and new climate change scenarios. Each boxplot is made from 27 data points – all nine cost and revenue scenarios for all three discount rates. The yellow points represent what is considered our best guess or default scenario – low cost, medium revenue and medium discount rate.

Key Findings

While our demonstration of the GaPP Tool is preliminary and intended to illustrate multiple applications of the tool, there are several takeaways from the examples presented that are important and can be drawn upon to increase efficacy of the tool in future implementations. These key findings include:

•Certain model parameters have more impact on model outputs than others (and not always the ones that are most intuitive)

•There may be threshold effects that can substantially affect profit

•Not all operational changes that benefit the environment negatively affect profit

The first key finding from the GaPP tool demonstration is that model outputs are more sensitive to some parameters. While this result is not surprising, it is important for KOMAZA to determine the sensitivity of all parameters in order to discover which parameters have the largest effect on model outputs. This is especially important if there is a high degree of uncertainty associated with a particular parameter. For uncertain parameters that are also sensitive, the model outputs become even more uncertain. This makes managing expectations and making a discrete optimal management decision more challenging. The first GaPP tool function can address this problem by performing a sensitivity analysis. Using results from the sensitivity analyses, KOMAZA can prioritize data collection for parameters with high sensitivity, high uncertainty and low collection costs. This use of the tool is shown in Example 1.1, which indicates that tree growth is more sensitive to soil fertility than to climate. This result becomes more interesting in the context of climate change. GaPP Tool Illustration 4.1.1 demonstrates that the impact of our climate change scenarios on growth is comparable to a decrease in soil fertility from high to medium. Therefore, assuming that our scenarios are an accurate representation of future climate change in the region, a significant decrease in a site's soil fertility could impact KOMAZA's profits more than changes in precipitation resulting from climate change.

The second key finding is that threshold effects can have a dramatic result on the optimal harvest age and associated profitability of a site and are not always easily discernible. This is important because dramatic changes in profit could negatively affect KOMAZA's ability to manage expectations of its farmers. In addition, the stark difference in profitability these threshold effects can create indicates that an averaged approach in deciding when to harvest may not always yield the best outcome. An example of a threshold effect is seen in Examples 1.5 and 3.2, where the minimum DBH needed to harvest a particular product has a detectable effect. In Example 1.5, which highlighted the sensitivity of growth and profit to the coppicing factor, GaPP Tool Illustration 1.5.2 shows the total profit attainable for both dry and wet climates when tree stands are harvested for either fuelwood or treated transmission poles. While the total profit for fuelwood mirrors the percent increase applied to growth by the coppicing factor, the total profit possible for treated transmission poles is either constant for each of the rotation periods (wet climate) or sees dramatic changes in profit between rotation periods (dry climate). This substantial difference between rotation periods is a consequence of the minimum DBH model parameter. Unlike fuelwood where revenue is solely based on the volume of the wood, trees harvested for transmission poles are not valuable until they reach a certain size, represented by the minimum DBH. Therefore, as is the case in the dry climate, whether or not a tree reaches this minimum DBH can be the difference between pronounced profits (rotation periods 2 and 3) and negative profit (rotation periods 1 and 4). The GaPP Tool can help determine these threshold effects through its ability to model different scenarios in any given model simulation, increasing the likelihood that the threshold effect is detected.

The third key finding is that not all management decisions that improve environmental quality (or mitigate environmental impacts) result in a trade-off with profitability. In order to permanently break the cycle of poverty and environmental degradation, KOMAZA's operations must be both financially sustainable and environmentally sustainable. While its primary objective is poverty alleviation, the secondary objective of environmental sustainability must be addressed in any long-term management strategy. The GaPP Tool allows KOMAZA to examine its operations to find "low-hanging fruit," or win-wins in which both profitability and environmental quality are improved. The GaPP Tool can also be used to discover management decisions that maintain profitability while simultaneously improving the environment. In this way, KOMAZA can systematically examine its operations to maximize profitability while improving the local environment. The GaPP tool can aid KOMAZA in prioritizing operational changes that are the most significant win-wins and the changes that are most cost-effective to implement. This approach will help KOMAZA meet its dual mission of poverty alleviation and environmental sustainability. Example 3.2 highlights this key finding. Under a dry climate, profitability is only decreased by 1% in scenarios where fertilizer use is decreased over time. Due to uncertainty in other parameter values, this result can be viewed as effectively having no change in profitability. Therefore, by changing its fertilizing practices, KOMAZA can maintain profitability while mitigating its impacts on the environment.

Appendix

Appendix A: Model inputs values used in GaPP Tool Demonstration

Input	Name	Parameter Values
Climate	Dry	See Appendix B1
	Average	See Appendix B2
	Wet	See Appendix B3
	Very Dry	See Appendix B4
	Dry & Unimodal	See Appendix B5
	Unimodal	See Appendix B6
Soil Fertility	Low	0.2
	Medium	0.5
	High	0.7
	S3 – S8	See Appendix C
Vegetation Parameters	*E. grandis camaldulensis* (E.GC)	See Appendix D
	E. globulus	See Appendix D
	Species DT	See Appendix D
Initial Costs	Low	11,185.90 (KSh)
	Medium	82,284.50 (KSh)
	High	115,355.63 (KSh)
	Other	See Appendix E
Annual Costs	Low	6,508.20 (KSh)
	Medium	60,012.79 (KSh)
	High	140,531.14 (KSh)
	Other	See Appendix E
Fuelwood Harvest Costs	Low	20,250 (KSh)
	Medium	27,000 (KSh)
	High	33,750 (KSh)
	Other	See Appendix E
Charcoal Harvest Costs	Low	40,500 (KSh)
	Medium	54,000 (KSh)
	High	67,500 (KSh)
Roundwood Harvest Costs	Low	20,250 (KSh)
	Medium	27,000 (KSh)
	High	33,750 (KSh)
Timber Harvest Costs	Low	415,500 (KSh)
	Medium	554,000 (KSh)
	High	692,500 (KSh)
Untreated Poles Harvest Costs	Low	20,250 (KSh)
	Medium	27,000 (KSh)
	High	54,000 (KSh)
	Other	See Appendix E
Treated Poles Harvest Costs	Low	415,500 (KSh)
	Medium	554,000 (KSh)
	High	560,750 (KSh)
	Other	See Appendix E

Fuelwood Market Price	Low Medium High	825 (KSh/m3) 1,100 (KSh/m3) 1,375 (KSh/m3)
Charcoal Market Price	Low Medium High	260 (KSh/bag) 430 (KSh/bag) 600 (KSh/bag)
Roundwood Market Price	Low Medium High	40 (KSh/tree) 100 (KSh/tree) 125 (KSh/tree)
Timber Market Price	Low Medium High	2,400 ((KSh/m3) 2,950 (KSh/m3) 3,500 (KSh/m3)
Untreated Poles Market Price	Low Medium High Other	1,012.50 (KSh/tree) 1,350 (KSh/tree) 1,687.5 (KSh/tree) See Appendix E
Treated Poles Market Price	Low Medium High Other	9,000 (KSh/tree) 12,000 ((KSh/tree) 15,000 (KSh/tree) See Appendix E

Appendix B1: Dry Climate Yearly Records

Appendix B1: Dry Climate Yearly Records (Mean Annual Precipitation = 631 mm)

Year	Input	Monthly Record												Annual Precipitation [mm]
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
	Tmax	31.7	31.9	32	31.7	28.8	28.3	28.4	28.2	29.2	30.7	32	32.8	
1	Tmin	23.6	23.3	23.6	23.5	22.7	21	20.1	18.7	21.4	21.9	22.9	23.7	
	Rain	43.9	21.1	114.1	62.2	119.8	61.1	71.8	32.8	75.9	30.1	29.5	24.6	686.9
	Tmax	31.8	32.8	33.2	31.5	30.8	29.2	27.8	28	28	30.6	31.3	33	
2	Tmin	22.1	22.1	23.2	23.8	23	21.6	20.7	19.9	20.5	22.1	22.7	23.9	
	Rain	19.2	16.9	42.6	98.7	85.5	46.3	68.8	28.7	38.8	32.5	84.1	29.2	591.3
	Tmax	33.6	33.8	33.7	30.5	31.2	29	28	27.7	29	30.7	31.5	33	
3	Tmin	24	24	24.5	23.6	23.2	21.1	21	19.8	19.7	21.9	22.6	23.1	
	Rain	21.3	27.2	52.9	54.1	73.6	46.9	100	59.5	30.6	77.8	33.6	22.9	600.4
	Tmax	33.2	33.4	32.7	31.7	28.8	28.3	27.6	28.2	29.1	30	30.8	31.4	
4	Tmin	22.8	22.6	23.8	23.5	22.7	21	19.9	20.7	20.8	21.5	22.7	23.4	
	Rain	23.3	16.9	26.8	62.2	119.8	61.1	44.5	38.6	22	84	103.4	72.5	675.1
	Tmax	30.7	31.7	32.8	32.3	29.9	28.9	27.4	28.2	28.9	30.7	31.5	33	
5	Tmin	23	23.9	23.8	23.8	22.7	21.4	20.1	20.6	20.7	21.9	22.6	23.1	
	Rain	47.6	18.1	22	89.4	172.3	69.5	42.4	42.9	44.9	77.8	33.6	22.9	683.4
	Tmax	31.8	32.8	33.2	32.1	30.1	29.4	28	27.7	29	30.2	31	30.2	
6	Tmin	22.1	22.1	23.2	23.4	21.7	20.7	21	19.8	19.7	21	22.3	23	
	Rain	19.2	16.9	42.6	96.9	180.2	20.9	100	59.5	30.6	31.2	40.5	28.2	666.7
	Tmax	33	33.3	33.4	31.6	29.9	28.3	27.4	28.2	28.9	29.7	31.3	31.6	
7	Tmin	24.1	24	24.2	23.6	23.2	21	20.1	20.6	20.7	21.2	22.8	23.4	
	Rain	33.9	22.1	21.4	66.3	124.6	93.4	42.4	42.9	44.9	29.6	44.1	100.7	666.3
	Tmax	32	32.8	33.9	33.3	29.4	28.6	28.7	29.2	30.3	29.9	31.5	31.8	
8	Tmin	21.9	22.2	23.2	25	22.5	21.3	21.3	21.3	22	20.7	21.6	23.3	
	Rain	17.3	17.1	32.7	43.2	250.2	81.7	38.3	35.1	21.2	30.2	61.7	32.5	661.2
	Tmax	33	33.3	33.4	31.9	31.6	28.7	28	28.5	29.7	30.2	31	30.2	
9	Tmin	24.1	24	24.2	24.8	24.4	21.6	20.8	20.5	21.3	21	22.3	23	
	Rain	33.9	22.1	21.4	62	32.9	87.1	54	40.3	27.4	31.2	40.5	28.2	481
	Tmax	33.2	33.4	32.7	31.4	29.8	28.5	27.9	28	29.1	29.9	31.5	31.8	
10	Tmin	22.8	22.6	23.8	23.2	22.1	20.8	20.3	19.2	20.6	20.7	21.6	23.3	
	Rain	23.3	16.9	26.8	110.4	133	95.3	29	49.7	32.2	30.2	61.7	32.5	641
	Tmax	31.9	29.8	33.1	31.7	28.8	28.3	28	28.5	29.7	30.5	30.8	31.8	
11	Tmin	23	22.5	24.2	23.5	22.7	21	20.8	20.5	21.3	20.7	22.5	22.8	
	Rain	30.5	18.9	37.5	62.2	119.8	61.1	54	40.3	27.4	56.5	34.3	42.7	585.2

Appendix B2: Average Climate Yearly Records

Appendix B2: Average Climate Yearly Records (Mean Annual Precipitation = 774 mm)														
Year	**Input**	**Monthly Record**												**Annual Precipitation [mm]**
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	
1	**Tmax**	33.1	32.8	33.4	33.3	29.4	28.6	28	28.5	29.7	30.7	31.5	33	
	Tmin	23.5	22.6	24.7	25	22.5	21.3	20.8	20.5	21.3	21.9	22.6	23.1	
	Rain	62	22	66.5	43.2	250.2	81.7	54	40.3	27.4	77.8	33.6	22.9	781.6
2	**Tmax**	33	33.3	33.4	31.6	30.4	29.1	27.1	27.5	28.5	29.2	31.5	31.7	
	Tmin	24.1	24	24.2	24.1	23.1	22	19.8	19.6	20.2	21.7	22.9	23.5	
	Rain	33.9	22.1	21.4	197.5	66.6	56.9	79.9	31.8	26.2	109.5	73.8	72.1	791.7
3	**Tmax**	32.1	31.5	33	30.8	28.2	29	27.9	28.1	28.9	29.9	31.5	31.8	
	Tmin	23.6	23.1	23.8	24.4	22.9	22.1	18.9	18.7	19.3	20.7	21.6	23.3	
	Rain	41.7	31	70.3	63.3	170.7	86.8	62.2	30.3	30.1	30.2	61.7	32.5	710.8
4	**Tmax**	31.8	32.8	33.2	30.4	29.8	28.8	27.9	28.1	28.9	30.3	31.2	32.1	
	Tmin	22.1	22.1	23.2	23.6	22.8	21.6	18.9	18.7	19.3	22.4	23.4	24	
	Rain	19.2	16.9	42.6	116.3	147.1	50.8	62.2	30.3	30.1	135.7	38.4	30.6	720.2
5	**Tmax**	31.8	32.1	32.9	31.9	31.6	28.7	27.9	27.7	28.9	30.3	31.3	30.5	
	Tmin	23	23.6	23.3	24.8	24.4	21.6	19.7	19.5	19.8	22	23.3	23	
	Rain	109.6	33.4	46	62	32.9	87.1	124.1	40.6	42.5	34.3	29.5	73.9	715.9
6	**Tmax**	32.7	32.3	32.6	31.6	29.9	28.3	28.1	27.9	28.8	29.2	31.5	31.7	
	Tmin	23.8	23	24.4	23.6	23.2	21	21.1	20.4	20.8	21.7	22.9	23.5	
	Rain	38.9	25.2	46.1	66.3	124.6	93.4	41.7	130.6	40.5	109.5	73.8	72.1	862.7
7	**Tmax**	33.2	33.4	32.7	31.5	30.4	28.9	28.4	28.2	29.2	29.7	31.3	31.6	
	Tmin	22.8	22.6	23.8	23.6	22.5	21.5	20.1	18.7	21.4	21.2	22.8	23.4	
	Rain	23.3	16.9	26.8	179	53.7	113.4	71.8	32.8	75.9	29.6	44.1	100.7	768
8	**Tmax**	32.1	31.5	33	30.8	28.2	29	27.6	28.2	29.1	29.4	31.6	31.9	
	Tmin	23.6	23.1	23.8	24.4	22.9	22.1	19.9	20.7	20.8	22.1	22.6	23.2	
	Rain	41.7	31	70.3	63.3	170.7	86.8	44.5	38.6	22	121.1	41.9	43.4	775.3
9	**Tmax**	33.2	33.4	32.7	31.6	29.9	28.3	27.9	28.1	28.9	30.2	31.6	33.2	
	Tmin	22.8	22.6	23.8	23.6	23.2	21	18.9	18.7	19.3	22.9	23.4	24.2	
	Rain	23.3	16.9	26.8	66.3	124.6	93.4	62.2	30.3	30.1	192.2	23.2	74.1	763.4
10	**Tmax**	31.6	32.3	33.2	31.5	29.4	29.2	28.3	28.6	28.6	30	31.1	31.9	
	Tmin	23.1	23.6	23.8	22.6	20.9	20.7	21.1	20.7	21.2	20.7	22.2	22.6	
	Rain	17.1	24.2	25.1	120.3	309.7	41.8	89	30.3	58.1	28.9	76.7	17.9	839.1
11	**Tmax**	31.9	29.8	33.1	31.9	29	28.9	28	28.5	29.7	30.2	31	30.2	
	Tmin	23	22.5	24.2	23.2	21.7	21.2	20.8	20.5	21.3	21	22.3	23	
	Rain	30.5	18.9	37.5	185.9	224.1	70.6	54	40.3	27.4	31.2	40.5	28.2	789.1

Appendix B3: Wet Climate Yearly Records

Appendix B3: Wet Climate Yearly Records (Mean Annual Precipitation = 1098 mm)

Year	Input	Monthly Record												Annual Precipitation [mm]
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
	Tmax	31.8	31.6	32.8	30.9	29.3	28.8	27.6	27.7	28.4	30.6	29.6	32	
1	Tmin	22.8	21.9	24	23.4	22.3	21.2	19.8	19.4	20.4	21.4	21.3	21.8	
	Rain	16.9	16.9	33.1	193.4	293.6	122.7	91.9	73	46.5	99.5	77.2	43.5	1108.2
	Tmax	31.7	31.9	32	33	30.8	29.8	27.7	28.1	28.4	30	30.3	31.2	
2	Tmin	23.6	23.3	23.6	24.9	23.6	22.5	20	19.9	20.4	21.8	21.6	21.9	
	Rain	43.9	21.1	114.1	62.3	77.6	71	106.5	50.8	79	66.6	127.2	99.8	919.9
	Tmax	31.8	32.1	32.9	31.9	29	28.9	27.8	28.5	30	30.9	32.2	32.6	
3	Tmin	23	23.6	23.3	23.2	21.7	21.2	20.7	20.8	20.6	21.9	22.6	23.2	
	Rain	109.6	33.4	46	185.9	224.1	70.6	41.4	35.8	25.9	38.9	47.2	63.2	922
	Tmax	33	32.9	33.2	30	29.5	28.3	28.3	28.8	29	29.7	31.3	31.6	
4	Tmin	23.5	23	23.8	23.1	22	21.4	20.9	20.7	20.8	21.2	22.8	23.4	
	Rain	21.7	17.2	36.8	220.5	251.6	76.6	40.7	70.2	51.9	29.6	44.1	100.7	961.6
	Tmax	31.7	31.9	32	31	28.8	28.2	27.6	28.2	29.1	30.5	31.9	32	
5	Tmin	23.6	23.3	23.6	23.5	22.2	21.6	19.9	20.7	20.8	21.6	23.1	23.1	
	Rain	43.9	21.1	114.1	289.1	335	96.6	44.5	38.6	22	39.5	27.1	38.5	1110
	Tmax	31.1	32.1	32.6	31.8	30	28.9	28.5	28.2	29.6	28.9	30.7	31.3	
6	Tmin	22.8	22.8	22.8	23.2	22.1	21.1	20.4	20.7	21.2	21.6	21.8	22.5	
	Rain	22.7	40.3	78.4	117	260	104.3	28.8	31.2	39.3	344.5	240.4	150	1456.9
	Tmax	30.7	31.7	32.8	32	30.5	28.7	27.8	28.5	30	28.9	30.7	31.3	
7	Tmin	23	23.9	23.8	24.3	22.8	21.2	20.7	20.8	20.6	21.6	21.8	22.5	
	Rain	47.6	18.1	22	57.8	128.2	99.5	41.4	35.8	25.9	344.5	240.4	150	1211.2
	Tmax	31.9	30.4	34.2	31.8	30	28.9	27.9	28.1	28.9	30	30.3	31.2	
8	Tmin	23.3	23.3	24.7	23.2	22.1	21.1	18.9	18.7	19.3	21.8	21.6	21.9	
	Rain	23.5	16.9	17	117	260	104.3	62.2	30.3	30.1	66.6	127.2	99.8	954.9
	Tmax	33.6	33.8	33.7	31.8	29.8	28	27.8	28.2	28.9	30.9	29	31.1	
9	Tmin	24	24	24.5	24.5	22.2	20.9	20.2	20.6	20.7	22.1	23.1	22.6	
	Rain	21.3	27.2	52.9	116.4	295.4	158.3	106	47	36.2	35.7	126.2	217.6	1240.2
	Tmax	32.7	32.3	32.6	30	29.5	28.3	28	27.5	29	30.2	29.3	31.8	
10	Tmin	23.8	23	24.4	23.1	22	21.4	20.2	20	20.8	21.5	22.5	23	
	Rain	38.9	25.2	46.1	220.5	251.6	76.6	59.8	51.4	33.2	123	82.5	71.7	1080.5
	Tmax	32	33.3	32.7	31.9	29	28.9	28.1	28.2	29.2	30.5	31.9	32	
11	Tmin	22.9	24	24.2	23.2	21.7	21.2	20.7	20.5	21	21.6	23.1	23.1	
	Rain	32.7	43.7	129.9	185.9	224.1	70.6	122.5	135.6	66.1	39.5	27.1	38.5	1116.2

Appendix B4: Very Dry Climate Yearly Records

Appendix B4: Very Dry Climate Yearly Records (Mean Annual Precipitation = 457 mm)

Year	Input	Monthly Record												Annual Precipitation [mm]
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
	Tmax	31.9	30.4	34.2	33.1	29.2	28.9	28.7	29.2	30.3	30.3	31.3	30.5	
1	Tmin	23.3	23.3	24.7	25.2	23.8	21.7	21.3	21.3	22	22	23.3	23	
	Rain	23.5	16.9	17	35.8	32.5	53.2	38.3	35.1	21.2	34.3	29.5	73.9	411.2
	Tmax	31.9	32.4	32.4	33.1	29.2	28.9	28.5	28.2	29.6	30.6	31.3	33	
2	Tmin	22.6	23.1	24.2	25.2	23.8	21.7	20.4	20.7	21.2	22.1	22.7	23.9	
	Rain	21.1	17.1	33.6	35.8	32.5	53.2	28.8	31.2	39.3	32.5	84.1	29.2	438.4
	Tmax	32.8	32.4	33.3	31.9	31.6	28.7	28.5	27.3	29.3	30.7	32	32.8	
3	Tmin	22.4	22.3	23.8	24.8	24.4	21.6	21.4	20.5	20.9	21.9	22.9	23.7	
	Rain	16.9	17.3	78.7	62	32.9	87.1	46.5	42.9	41.7	30.1	29.5	24.6	510.2
	Tmax	31.9	30.4	34.2	33.1	29.2	28.9	28.7	29.2	30.3	30.3	31.3	30.5	
4	Tmin	23.3	23.3	24.7	25.2	23.8	21.7	21.3	21.3	22	22	23.3	23	
	Rain	23.5	16.9	17	35.8	32.5	53.2	38.3	35.1	21.2	34.3	29.5	73.9	411.2
	Tmax	32.6	32.7	33.5	31.5	30.8	29.2	27.9	28	29.1	30.7	32	32.8	
5	Tmin	23.3	23.8	24.7	23.8	23	21.6	20.3	19.2	20.6	21.9	22.9	23.7	
	Rain	18.1	19.3	28.9	98.7	85.5	46.3	29	49.7	32.2	30.1	29.5	24.6	491.9
	Tmax	32	32.8	33.9	33	30.8	29.8	27.8	28	28	29.8	30.5	31.4	
6	Tmin	21.9	22.2	23.2	24.9	23.6	22.5	20.7	19.9	20.5	21.3	22.4	23.2	
	Rain	17.3	17.1	32.7	62.3	77.6	71	68.8	28.7	38.8	33.3	31.6	39	518.2
	Tmax	33.6	33.8	33.7	33.1	29.2	28.9	28.5	28.2	29.6	29.8	30.5	31.4	
7	Tmin	24	24	24.5	25.2	23.8	21.7	20.4	20.7	21.2	21.3	22.4	23.2	
	Rain	21.3	27.2	52.9	35.8	32.5	53.2	28.8	31.2	39.3	33.3	31.6	39	426.1
	Tmax	32	32.3	32.7	30.5	31.2	29	27.9	28.1	28.9	30	31.1	31.9	
8	Tmin	22.9	23.3	24.1	23.6	23.2	21.1	18.9	18.7	19.3	20.7	22.2	22.6	
	Rain	16.9	18.1	25.4	54.1	73.6	46.9	62.2	30.3	30.1	28.9	76.7	17.9	481.1
	Tmax	32	32.8	33.9	33.1	29.2	28.9	27.1	27.5	28.5	30.5	30.8	31.8	
9	Tmin	21.9	22.2	23.2	25.2	23.8	21.7	19.8	19.6	20.2	20.7	22.5	22.8	
	Rain	17.3	17.1	32.7	35.8	32.5	53.2	79.9	31.8	26.2	56.5	34.3	42.7	460
	Tmax	33.6	33.8	33.7	33.1	29.2	28.9	28.5	28.2	29.6	29.8	30.5	31.4	
10	Tmin	24	24	24.5	25.2	23.8	21.7	20.4	20.7	21.2	21.3	22.4	23.2	
	Rain	21.3	27.2	52.9	35.8	32.5	53.2	28.8	31.2	39.3	33.3	31.6	39	426.1
	Tmax	32.6	32.7	33.5	33.1	29.2	28.9	27.4	28.2	28.9	30.3	31.3	30.5	
11	Tmin	23.3	23.8	24.7	25.2	23.8	21.7	20.1	20.6	20.7	22	23.3	23	
	Rain	18.1	19.3	28.9	35.8	32.5	53.2	42.4	42.9	44.9	34.3	29.5	73.9	455.7

Appendix B5: Dry & Unimodal Climate Yearly Records

Appendix B5: Dry & Unimodal Climate Yearly Records (Mean Annual Precipitation = 635 mm)														
Year	Input	Monthly Record												Annual Precipitation [mm]
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1	Tmax	32	32.8	33.9	33.3	29.4	28.6	28.7	29.2	30.3	29.9	31.5	31.8	
	Tmin	21.9	22.2	23.2	25	22.5	21.3	21.3	21.3	22	20.7	21.6	23.3	
	Rain	17.3	17.1	32.7	43.2	250.2	81.7	38.3	35.1	21.2	30.2	61.7	32.5	661.2
2	Tmax	31.6	32.3	32.6	31.6	29.9	28.3	28.5	28.2	29.6	30.7	32	32.8	
	Tmin	23.4	23.3	24.5	23.6	23.2	21	20.4	20.7	21.2	21.9	22.9	23.7	
	Rain	17.1	22.4	22.3	66.3	124.6	93.4	28.8	31.2	39.3	30.1	29.5	24.6	529.6
3	Tmax	33	33.3	33.4	33.3	29.4	28.6	27.8	28.5	30	29.9	31.5	31.8	
	Tmin	24.1	24	24.2	25	22.5	21.3	20.7	20.8	20.6	20.7	21.6	23.3	
	Rain	33.9	22.1	21.4	43.2	250.2	81.7	41.4	35.8	25.9	30.2	61.7	32.5	680
4	Tmax	32.6	32.7	33.5	33.3	29.4	28.6	27.6	28.2	29.1	30.3	31.3	30.5	
	Tmin	23.3	23.8	24.7	25	22.5	21.3	19.9	20.7	20.8	22	23.3	23	
	Rain	18.1	19.3	28.9	43.2	250.2	81.7	44.5	38.6	22	34.3	29.5	73.9	684.2
5	Tmax	31.9	32.4	32.4	33.3	29.4	28.6	28.7	29.2	30.3	30.7	32	32.8	
	Tmin	22.6	23.1	24.2	25	22.5	21.3	21.3	21.3	22	21.9	22.9	23.7	
	Rain	21.1	17.1	33.6	43.2	250.2	81.7	38.3	35.1	21.2	30.1	29.5	24.6	625.7
6	Tmax	31.6	32.3	32.6	31.8	30.9	29.6	28.5	28.2	29.6	30	31.1	31.9	
	Tmin	23.4	23.3	24.5	24.2	22.9	21.4	20.4	20.7	21.2	20.7	22.2	22.6	
	Rain	17.1	22.4	22.3	77	163.3	75.5	28.8	31.2	39.3	28.9	76.7	17.9	600.4
7	Tmax	31.9	30.4	34.2	33	30.1	29.1	27.8	28.5	30	30.7	32	32.8	
	Tmin	23.3	23.3	24.7	24.5	22.7	20.9	20.7	20.8	20.6	21.9	22.9	23.7	
	Rain	23.5	16.9	17	81.9	186.6	57.5	41.4	35.8	25.9	30.1	29.5	24.6	570.7
8	Tmax	31.8	31.6	32.8	32.3	29.9	28.9	27.9	28	29.1	30.2	31	30.2	
	Tmin	22.8	21.9	24	23.8	22.7	21.4	20.3	19.2	20.6	21	22.3	23	
	Rain	16.9	16.9	33.1	89.4	172.3	69.5	29	49.7	32.2	31.2	40.5	28.2	608.9
9	Tmax	31.6	32.3	32.6	31.7	30	28.4	28.5	27.3	29.3	30.9	32.2	32.6	
	Tmin	23.4	23.3	24.5	23.7	22.2	21.1	21.4	20.5	20.9	21.9	22.6	23.2	
	Rain	17.1	22.4	22.3	101.2	106	149.9	46.5	42.9	41.7	38.9	47.2	63.2	699.3
10	Tmax	31.9	32.4	32.4	33.1	29.2	28.9	27.9	28	29.1	30.9	29	31.1	
	Tmin	22.6	23.1	24.2	25.2	23.8	21.7	20.3	19.2	20.6	22.1	23.1	22.6	
	Rain	21.1	17.1	33.6	35.8	32.5	53.2	29	49.7	32.2	35.7	126.2	217.6	683.7
11	Tmax	31.9	30.4	34.2	31.7	30	28.4	28.5	27.3	29.3	30.2	31	30.2	
	Tmin	23.3	23.3	24.7	23.7	22.2	21.1	21.4	20.5	20.9	21	22.3	23	
	Rain	23.5	16.9	17	101.2	106	149.9	46.5	42.9	41.7	31.2	40.5	28.2	645.5

Appendix B6: Unimodal Climate Yearly Records

Appendix B6: Unimodal Climate Yearly Records (Mean Annual Precipitation = 956 mm)

Year	Input	Monthly Record												Annual Precipitation [mm]
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1	Tmax	31.9	29.8	33.1	31	28.8	28.2	28	28.5	29.7	30.5	31.9	32	
	Tmin	23	22.5	24.2	23.5	22.2	21.6	20.8	20.5	21.3	21.6	23.1	23.1	
	Rain	30.5	18.9	37.5	289.1	335	96.6	54	40.3	27.4	39.5	27.1	38.5	1034.4
2	Tmax	32.2	32.4	32.9	31	28.8	28.2	27.9	28	29.1	29.8	30.5	31.4	
	Tmin	23.6	23.7	24.4	23.5	22.2	21.6	20.3	19.2	20.6	21.3	22.4	23.2	
	Rain	18.8	16.9	69.7	289.1	335	96.6	29	49.7	32.2	33.3	31.6	39	1040.9
3	Tmax	32	33.1	33.3	31.5	29.5	28.6	28.7	29.2	30.3	30.3	31.3	30.5	
	Tmin	22.6	23.1	23.8	23.2	22.1	21.1	21.3	21.3	22	22	23.3	23	
	Rain	17.1	16.9	25.4	287.2	353.7	45.6	38.3	35.1	21.2	34.3	29.5	73.9	978.2
4	Tmax	33	33.3	33.4	31.8	29.8	28	28.7	29.2	30.3	30.7	31.5	33	
	Tmin	24.1	24	24.2	24.5	22.2	20.9	21.3	21.3	22	21.9	22.6	23.1	
	Rain	33.9	22.1	21.4	116.4	295.4	158.3	38.3	35.1	21.2	77.8	33.6	22.9	876.4
5	Tmax	33	33.3	33.4	30	29.5	28.3	28.7	29.2	30.3	29.7	31.3	31.6	
	Tmin	24.1	24	24.2	23.1	22	21.4	21.3	21.3	22	21.2	22.8	23.4	
	Rain	33.9	22.1	21.4	220.5	251.6	76.6	38.3	35.1	21.2	29.6	44.1	100.7	895.1
6	Tmax	32	32.8	33.9	30	29.5	28.3	28.5	28.2	29.6	30.3	31.3	30.5	
	Tmin	21.9	22.2	23.2	23.1	22	21.4	20.4	20.7	21.2	22	23.3	23	
	Rain	17.3	17.1	32.7	220.5	251.6	76.6	28.8	31.2	39.3	34.3	29.5	73.9	852.8
7	Tmax	33	33.3	33.4	30.9	29.3	28.8	28.7	29.2	30.3	30.5	30.8	31.8	
	Tmin	24.1	24	24.2	23.4	22.3	21.2	21.3	21.3	22	20.7	22.5	22.8	
	Rain	33.9	22.1	21.4	193.4	293.6	122.7	38.3	35.1	21.2	56.5	34.3	42.7	915.2
8	Tmax	31.6	32.3	32.6	31.5	29.5	28.6	28.5	27.3	29.3	30.7	30.3	32	
	Tmin	23.4	23.3	24.5	23.2	22.1	21.1	21.4	20.5	20.9	21.5	22.3	22.9	
	Rain	17.1	22.4	22.3	287.2	353.7	45.6	46.5	42.9	41.7	33.2	87.8	65.7	1066.1
9	Tmax	31.9	29.8	33.1	31	28.8	28.2	27.9	28.1	28.9	30.7	32	32.8	
	Tmin	23	22.5	24.2	23.5	22.2	21.6	18.9	18.7	19.3	21.9	22.9	23.7	
	Rain	30.5	18.9	37.5	289.1	335	96.6	62.2	30.3	30.1	30.1	29.5	24.6	1014.4
10	Tmax	31.8	32.8	33.2	31	28.8	28.2	27.8	28	28	30	31.1	31.9	
	Tmin	22.1	22.1	23.2	23.5	22.2	21.6	20.7	19.9	20.5	20.7	22.2	22.6	
	Rain	19.2	16.9	42.6	289.1	335	96.6	68.8	28.7	38.8	28.9	76.7	17.9	1059.2
11	Tmax	32	33.1	33.3	31.8	30	28.9	28	28.5	29.7	29.9	31.5	31.8	
	Tmin	22.6	23.1	23.8	23.2	22.1	21.1	20.8	20.5	21.3	20.7	21.6	23.3	
	Rain	17.1	16.9	25.4	117	260	104.3	54	40.3	27.4	30.2	61.7	32.5	786.8

Appendix C: Example 3.2 Soil Fertility Scenarios

Scenario	Soil Fertility Rating	Age of Tree
S3	0.7	1-20
S4	0.8	1-7
	0.7	8-14
	0.6	15-20
S5	0.9	1-4
	0.8	5-8
	0.7	9-12
	0.6	13-16
	0.5	17-20
S6	0.7	1-10
	0.5	11-20
S7	0.7	1-12
	0.5	13-20
S8	0.7	1-14
	0.5	15-20

Appendix D: Vegetation Parameters

Meaning/comments	Name	Units	E. GC	*E. globulus*	Species DT
Allometric relationships & partitioning					
Foliage:stem partitioning ratio @ D=2 cm	pFS2	-	1	1	1
Foliage:stem partitioning ratio @ D=20 cm	pFS20	-	0.15	0.15	0.15
Constant in the stem mass v. diam. relationship	StemConst	?	0.112	0.095	0.112
Power in the stem mass v. diam. relationship	StemPower	-	2.4	2.4	2.4
Maximum fraction of NPP to roots	pRx	-	0.8	0.8	0.8
Minimum fraction of NPP to roots	pRn	-	0.2	0.25	0.25
Temperature modifier (fT)					
Minimum temperature for growth	Tmin	deg. C	5	8.5	5
Optimum temperature for growth	Topt	deg. C	24	16	24
Maximum temperature for growth	Tmax	deg. C	36	40	36
Frost modifier (fFRost)					
Days production lost per frost day	kF	days	1	0	1
Soil water modifier (fSW)					
Moisture ratio deficit for f_q = 0.5	SWconst	-	0.7	0.7	0.7
Power of moisture ratio deficit	SWpower	-	9	9	9
Fertitlity effects					
Value of 'm' when FR = 0	m0	-	0.5	0	0.5
Value of 'fNutr' when FR = 0	fN0	-	0.3	1	0.3
Age modifier (fAge)					
Maximum stand age used in age modifier	MaxAge	years	50	50	50
Power of relative age in function for fAge	nAge	-	4	4	4
Relative age to give fAge = 0.5	rAge	-	0.95	0.95	0.95
Litterfall & root turnover					
Maximum litterfall rate	gammaFx	1/month	0.07	0.027	0.07
Litterfall rate at t = 0	gammaF0	1/month	0.001	0.001	0.001
Age at which litterfall rate has median value	tgammaF	month	24	12	24
Average monthly root turnover rate	Rttover	1/month	0.015	0.015	0.013
Conductance					
Maximum canopy conductance	MaxCond	m/s	0.03	0.02	0.03
LAI for maximum canopy conductance	LAIgcx	-	3.33	3.33	3.33
Defines stomatal response to VPD	CoeffCond	1/mBar	0.05	0.05	0.05
Canopy boundary layer conductance	BLcond	m/s	0.2	0.2	0.2
Max. stem mass per tree @ 1000 trees/hectare	wSx1000	kg/tree	300	300	300
Power in self-thinning rule	thinPower	-	1.5	1.5	1.5
Fraction mean single-tree foliage biomass lost per dead tree	mF	-	0	0	0
Fraction mean single-tree root biomass lost per dead tree	mR	-	0.2	0.2	0.2
Fraction mean single-tree stem biomass lost per dead tree	mS	-	0.2	0.2	0.2
Canopy structure and processes					
Specific leaf area at age 0	SLA0	m^2/kg	7.6	11	7.6
Specific leaf area for mature leaves	SLA1	m^2/kg	7.6	4	7.6
Age at which specific leaf area = (SLA0+SLA1)/2	tSLA	years	2.5	2.5	2.5
Extinction coefficient for absorption of PAR by canopy	k	-	0.45	0.5	0.45
Age at canopy cover	fullCanAge	years	0	0	0
Maximum proportion of rainfall evaporated from canopy	MaxIntcptn	-	0.04	0.15	0.04
LAI for maximum rainfall interception	LAImaxIntcptn	-	0	0	0
Canopy quantum efficiency	alpha	molC/molPAR	0.07	0.06	0.07
Branch and bark fraction (fracBB)					
Branch and bark fraction at age 0	fracBB0	-	0.3	0.75	0.3
Branch and bark fraction for mature stands	fracBB1	-	0.1	0.15	0.1
Age at which fracBB = (fracBB0+fracBB1)/2	tBB	years	3.5	2	3.5
Various					
Ratio NPP/GPP	Y	-	0.47	0.47	0.49
Basic density	Density	t/m3	0.500	0.450	0.500
Conversion factors					
Intercept of net v. solar radiation relationship	Qa	W/m2	-90	-90	-90
Slope of net v. solar radiation relationship	Qb	-	0.8	0.8	0.8
Molecular weight of dry matter	gDM_mol	gDM/mol	24	24	24
Conversion of solar radiation to PAR	molPAR_MJ	mol/MJ	2.3	2.3	2.3

Appendix E: Additional Cost and Market Price Parameter Values

Input	Example(s) Used In	Parameter Values
Fuelwood Harvest Costs 1-6	Example 1.4	5,000 (KSh) 10,000 (KSh) 20,000 (KSh) 50,000 (KSh) 100,000 (KSh) 200,000 (KSh)
Untreated Poles Harvest Costs 1-6	Example 3.3	10,000 (KSh) 25,000 (KSh) 75,000 (KSh) 150,000 (KSh) 300,000 (KSh) 600,000 (KSh)
Treated Poles Harvest Costs 1-6	Example 3.3	20,000 (KSh) 50,000 (KSh) 100,000 (KSh) 200,000 (KSh) 500,000 (KSh) 1,000,000 (KSh)
Initial Costs	Examples 1.3, 2.1	20,658.4 (KSh) 83,284.5 (KSh) 115,355.63 (KSh)
Annual Costs	Examples 1.3, 2.1	1,575 (KSh) 60,012.79 (KSh) 179,996.71 (KSh)
Untreated Poles Market Prices (Low, Medium, High, Very High)	Example 3.3	800 (KSh) 1,350 (KSh) 2,000 (KSh) 4,000 (KSh)
Treated Poles Market Prices (Very Low)	Example 3.3	3,000 (KSh)

Appendix F: Profit Model R Code

```
################################
#### Reading in 3PG results ####
################################
dbh = read.csv("3PG-results-fert.csv", header=T)
dbh.colnames = colnames(dbh)
epg.scen = dbh.colnames[2:ncol(dbh)]
standvol = read.csv("3PG-results-vol-fert.csv", header=T)

############################
#### Initial parameters ####
############################
parameters = read.csv("MODEL_Parameters.csv", header=F)
max.age = as.numeric(as.vector(parameters[1,2]))
max.years = as.numeric(as.vector(parameters[2,2]))
hectares = as.numeric(as.vector(parameters[3,2]))
stocking = as.numeric(as.vector(parameters[4,2]))
discount.rate.low = as.numeric(as.vector(parameters[5,2]))
discount.rate.med = as.numeric(as.vector(parameters[6,2]))
discount.rate.high = as.numeric(as.vector(parameters[7,2]))
product1 = as.character(parameters[8,2])
product2 = as.character(parameters[9,2])
product3 = as.character(parameters[10,2])
product4 = as.character(parameters[11,2])
product5 = as.character(parameters[12,2])
product6 = as.character(parameters[13,2])
coppice1 = as.numeric(as.vector(parameters[14,2]))  #Coppice effect after first harvest
coppice2 = as.numeric(as.vector(parameters[15,2]))  #Coppice effect after second harvest
coppice3 = as.numeric(as.vector(parameters[16,2]))  #Coppice effect after third harvest

######################################
#### Revenue functions parameters ####
######################################
  #parameters
charcoal.bag.factor = as.numeric(as.vector(parameters[17,2]))  # How many standard bags of
Charcoal per m3 wood
product1.min.dbh = as.numeric(as.vector(parameters[18,2]))
product2.min.dbh = as.numeric(as.vector(parameters[19,2]))
product3.min.dbh = as.numeric(as.vector(parameters[20,2]))
```

```
product4.min.dbh = as.numeric(as.vector(parameters[21,2]))
product5.min.dbh = as.numeric(as.vector(parameters[22,2]))
product6.min.dbh = as.numeric(as.vector(parameters[23,2]))
  #market prices
product1.market.price.low = as.numeric(as.vector(parameters[24,2]))
product1.market.price.med = as.numeric(as.vector(parameters[25,2]))
product1.market.price.high = as.numeric(as.vector(parameters[26,2]))
product2.market.price.low = as.numeric(as.vector(parameters[27,2]))
product2.market.price.med = as.numeric(as.vector(parameters[28,2]))
product2.market.price.high = as.numeric(as.vector(parameters[29,2]))
product3.market.price.low = as.numeric(as.vector(parameters[30,2]))
product3.market.price.med = as.numeric(as.vector(parameters[31,2]))
product3.market.price.high = as.numeric(as.vector(parameters[32,2]))
product4.market.price.low = as.numeric(as.vector(parameters[33,2]))
product4.market.price.med = as.numeric(as.vector(parameters[34,2]))
product4.market.price.high = as.numeric(as.vector(parameters[35,2]))
product5.market.price.low = as.numeric(as.vector(parameters[36,2]))
product5.market.price.med = as.numeric(as.vector(parameters[37,2]))
product5.market.price.high = as.numeric(as.vector(parameters[38,2]))
product6.market.price.low = as.numeric(as.vector(parameters[39,2]))
product6.market.price.med = as.numeric(as.vector(parameters[40,2]))
product6.market.price.high = as.numeric(as.vector(parameters[41,2]))

###################################
#### Cost functions parameters ####
###################################
harvest.size.cost = as.numeric(as.vector(parameters[42,2]))
  #initial costs
init.cost.low = as.numeric(as.vector(parameters[43,2]))
init.cost.med = as.numeric(as.vector(parameters[44,2]))
init.cost.high = as.numeric(as.vector(parameters[45,2]))
  #annual costs
annual.cost.low = as.numeric(as.vector(parameters[46,2]))
annual.cost.med = as.numeric(as.vector(parameters[47,2]))
annual.cost.high = as.numeric(as.vector(parameters[48,2]))
  #harvest costs
product1.harvest.cost.low = as.numeric(as.vector(parameters[49,2]))
product1.harvest.cost.med = as.numeric(as.vector(parameters[50,2]))
```

```
product1.harvest.cost.high = as.numeric(as.vector(parameters[51,2]))
product2.harvest.cost.low = as.numeric(as.vector(parameters[52,2]))
product2.harvest.cost.med = as.numeric(as.vector(parameters[53,2]))
product2.harvest.cost.high = as.numeric(as.vector(parameters[54,2]))
product3.harvest.cost.low = as.numeric(as.vector(parameters[55,2]))
product3.harvest.cost.med = as.numeric(as.vector(parameters[56,2]))
product3.harvest.cost.high = as.numeric(as.vector(parameters[57,2]))
product4.harvest.cost.low = as.numeric(as.vector(parameters[58,2]))
product4.harvest.cost.med = as.numeric(as.vector(parameters[59,2]))
product4.harvest.cost.high = as.numeric(as.vector(parameters[60,2]))
product5.harvest.cost.low = as.numeric(as.vector(parameters[61,2]))
product5.harvest.cost.med = as.numeric(as.vector(parameters[62,2]))
product5.harvest.cost.high = as.numeric(as.vector(parameters[63,2]))
product6.harvest.cost.low = as.numeric(as.vector(parameters[64,2]))
product6.harvest.cost.med = as.numeric(as.vector(parameters[65,2]))
product6.harvest.cost.high = as.numeric(as.vector(parameters[66,2]))

#########################
#### Creating Arrays ####
#########################
product = c(1:6)
product[1] = product1
product[2] = product2
product[3] = product3
product[4] = product4
product[5] = product5
product[6] = product6
rp = c(1:4)
age = c(1:max.age)

##############################################
#### Creating matrix for profit scenarios ####
##############################################
scen.profit = expand.grid(age, rp, product, epg.scen)
colnames(scen.profit) = c("age","rp","product","epg.scen")

#adding dbh and ID columns to scen.profit matrix
dbh.array = as.data.frame(matrix(nrow=(ncol(dbh)-1), ncol=3))
```

```
for (i in 2:ncol(dbh)) {
  for (j in 1:20) {
    index = (i-2)*20 + j
    dbh.array[index,1] = dbh[j,i]
    dbh.array[index,2] = standvol[j,i]
    dbh.array[index,3] = j
    dbh.array[index,4] = colnames(dbh)[i]
    dbh.array[index,5] = index
  }
}
colnames(dbh.array) = c("dbh", "standvol", "age", "epg.scen", "ID")
scen.profit$dbh = 0.0
scen.profit$standvol = 0.0

for (i in 1:nrow(scen.profit)) {
  dbh.scen.profit = subset(dbh.array$dbh, dbh.array$age==scen.profit$age[i] & dbh.array$epg.scen == scen.profit$epg.scen[i])
  standvol.scen.profit = subset(dbh.array$standvol, dbh.array$age==scen.profit$age[i] & dbh.array$epg.scen == scen.profit$epg.scen[i])
   ID = subset(dbh.array$ID, dbh.array$age==scen.profit$age[i] & dbh.array$epg.scen==scen.profit$epg.scen[i])
  scen.profit$dbh[i] = dbh.scen.profit
  scen.profit$standvol[i] = standvol.scen.profit
  scen.profit$ID[i] = ID
}

  #COPPICING FUNCTION
copfunction = ifelse(scen.profit$rp==1, 1, ifelse(scen.profit$rp==2, coppice1,ifelse(scen.profit$rp==3, coppice2, coppice3)))
scen.profit$dbh = scen.profit$dbh*copfunction
scen.profit$standvol = scen.profit$standvol*copfunction

############################
#### Revenue functions #####
############################
product1.revenue.low = ifelse(scen.profit$dbh<product1.min.dbh,0,scen.profit$standvol*hectares*product1.market.price.low)
product1.revenue.med = ifelse(scen.profit$dbh<product1.min.dbh,0,scen.profit$standvol*hectares*product1.market.price.med)
```

```
product1.revenue.high = ifelse(scen.profit$dbh<product1.min.dbh,0,scen.profit$standvol*hectares*product1.market.price.high)

product2.revenue.low = ifelse(scen.profit$dbh<product2.min.dbh,0,scen.profit$standvol*hectares*product2.market.price.low*charcoal.bag.factor)

product2.revenue.med = ifelse(scen.profit$dbh<product2.min.dbh,0,scen.profit$standvol*hectares*product2.market.price.med*charcoal.bag.factor)

product2.revenue.high = ifelse(scen.profit$dbh<product2.min.dbh,0,scen.profit$standvol*hectares*product2.market.price.high*charcoal.bag.factor)

product3.revenue.low = ifelse(scen.profit$dbh<product3.min.dbh,0,stocking*hectares*(product3.market.price.low))

product3.revenue.med = ifelse(scen.profit$dbh<product3.min.dbh,0,stocking*hectares*(product3.market.price.med))

product3.revenue.high = ifelse(scen.profit$dbh<product3.min.dbh,0,stocking*hectares*(product3.market.price.high))

product4.revenue.low = ifelse(scen.profit$dbh<product4.min.dbh,0,scen.profit$standvol*hectares*product4.market.price.low)

product4.revenue.med = ifelse(scen.profit$dbh<product4.min.dbh,0,scen.profit$standvol*hectares*product4.market.price.med)

product4.revenue.high = ifelse(scen.profit$dbh<product4.min.dbh,0,scen.profit$standvol*hectares*product4.market.price.high)

product5.revenue.low = ifelse(scen.profit$dbh<product5.min.dbh,0,stocking*hectares*(product5.market.price.low))

product5.revenue.med = ifelse(scen.profit$dbh<product5.min.dbh,0,stocking*hectares*(product5.market.price.med))

product5.revenue.high = ifelse(scen.profit$dbh<product5.min.dbh,0,stocking*hectares*(product5.market.price.high))

product6.revenue.low = ifelse(scen.profit$dbh<product6.min.dbh,0,stocking*hectares*(product6.market.price.low))

product6.revenue.med = ifelse(scen.profit$dbh<product6.min.dbh,0,stocking*hectares*(product6.market.price.med))

product6.revenue.high = ifelse(scen.profit$dbh<product6.min.dbh,0,stocking*hectares*(product6.market.price.high))


#########################

#### Cost functions #####

#########################

harvest.size.penalty = harvest.size.cost*scen.profit$dbh #Applies extra harvest costs as a function of dbh

product1.cost.low = product1.harvest.cost.low + annual.cost.low*scen.profit$age + init.cost.low + harvest.size.penalty

product1.cost.med = product1.harvest.cost.med + annual.cost.med*scen.profit$age + init.cost.med + harvest.size.penalty

product1.cost.high = product1.harvest.cost.high + annual.cost.high*scen.profit$age + init.cost.high + harvest.size.penalty
```

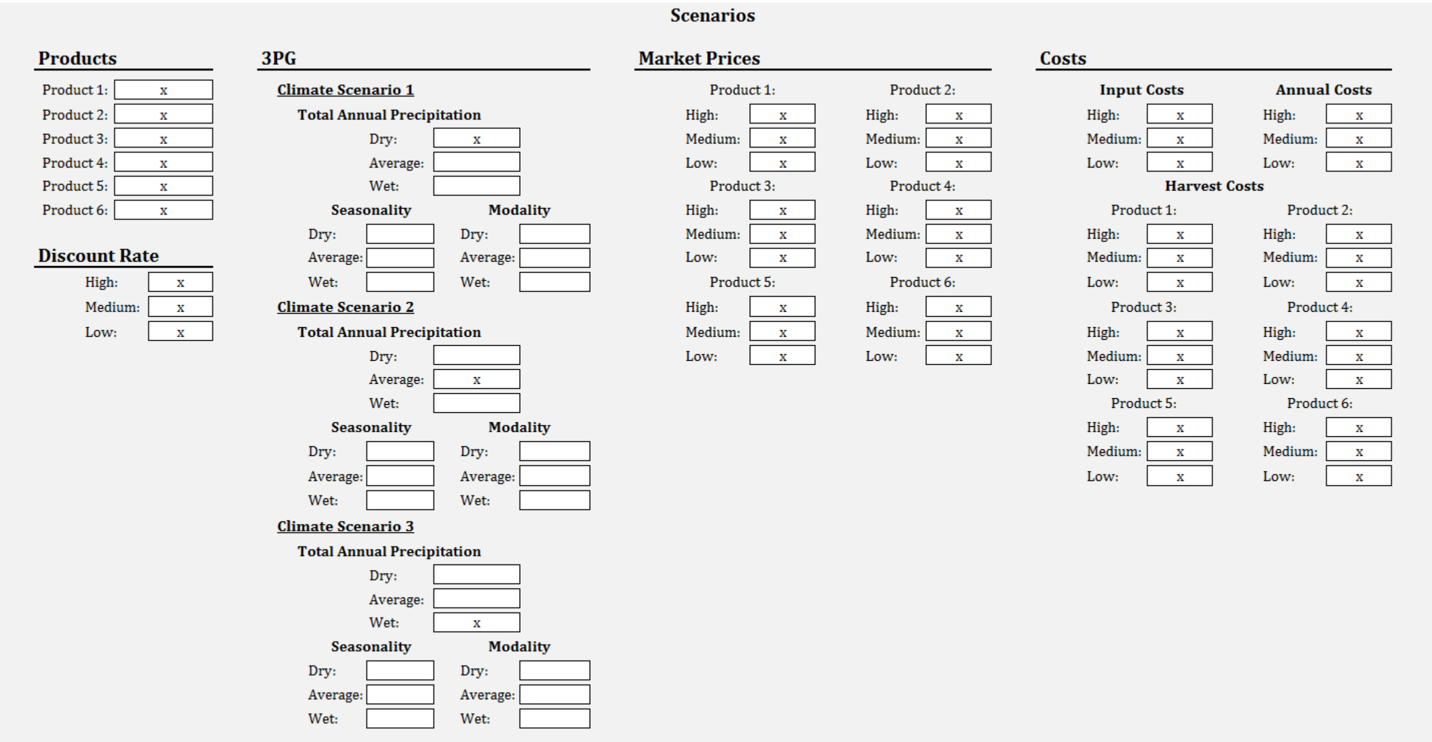
```
product2.cost.low  =  product2.harvest.cost.low  +  annual.cost.low*scen.profit$age  +  init.
cost.low + harvest.size.penalty

product2.cost.med  =  product2.harvest.cost.med  +  annual.cost.med*scen.profit$age  +  init.
cost.med + harvest.size.penalty

product2.cost.high = product2.harvest.cost.high + annual.cost.high*scen.profit$age + init.
cost.high + harvest.size.penalty

product3.cost.low  =  product3.harvest.cost.low  +  annual.cost.low*scen.profit$age  +  init.
cost.low + harvest.size.penalty

product3.cost.med  =  product3.harvest.cost.med  +  annual.cost.med*scen.profit$age  +  init.
cost.med + harvest.size.penalty

product3.cost.high = product3.harvest.cost.high + annual.cost.high*scen.profit$age + init.
cost.high + harvest.size.penalty

product4.cost.low  =  product4.harvest.cost.low  +  annual.cost.low*scen.profit$age  +  init.
cost.low + harvest.size.penalty

product4.cost.med  =  product4.harvest.cost.med  +  annual.cost.med*scen.profit$age  +  init.
cost.med + harvest.size.penalty

product4.cost.high = product4.harvest.cost.high + annual.cost.high*scen.profit$age + init.
cost.high + harvest.size.penalty

product5.cost.low  =  product5.harvest.cost.low  +  annual.cost.low*scen.profit$age  +  init.
cost.low + harvest.size.penalty

product5.cost.med  =  product5.harvest.cost.med  +  annual.cost.med*scen.profit$age  +  init.
cost.med + harvest.size.penalty

product5.cost.high = product5.harvest.cost.high + annual.cost.high*scen.profit$age + init.
cost.high + harvest.size.penalty

product6.cost.low  =  product6.harvest.cost.low  +  annual.cost.low*scen.profit$age  +  init.
cost.low + harvest.size.penalty

product6.cost.med  =  product6.harvest.cost.med  +  annual.cost.med*scen.profit$age  +  init.
cost.med + harvest.size.penalty

product6.cost.high = product6.harvest.cost.high + annual.cost.high*scen.profit$age + init.
cost.high + harvest.size.penalty


######################################

######################################

#### LOW COST LOW REVENUE SCENARIO ###

######################################

######################################

#Low Cost Scenario

cost.function.low = ifelse(scen.profit$product==product1, product1.cost.low, ifelse(scen.
profit$product==product2,  product2.cost.low,  ifelse(scen.profit$product==product3,  prod-
uct3.cost.low,   ifelse(scen.profit$product==product4,   product4.cost.low,   ifelse(scen.
profit$product==product5, product5.cost.low, product6.cost.low )))))

scen.profit$cost = cost.function.low
```

```
#Low Renevue Scenario

rev.function.low = ifelse(scen.profit$product==product1, product1.revenue.low, ifelse(scen.
profit$product==product2, product2.revenue.low, ifelse(scen.profit$product==product3, prod-
uct3.revenue.low, ifelse(scen.profit$product==product4, product4.revenue.low, ifelse(scen.
profit$product==product5, product5.revenue.low, product6.revenue.low )))))

scen.profit$revenue = rev.function.low

#Profit

scen.profit$profit = scen.profit$revenue - scen.profit$cost


ids = unique(scen.profit$ID)

nids = length(ids)

ncol=9

result = as.data.frame(matrix(nrow=nids, ncol=ncol))

colnames(result)=c("ID","total_profit","discounted_profit_low","discounted_profit_
med","discounted_profit_high","product_rp1", "product_rp2", "product_rp3", "product_rp4")

nyears = max.years

maxrp = 4


for (i in 1:nids) {

  id = ids[i]

  curr = subset(scen.profit, scen.profit$ID==id & scen.profit$rp == 1 & scen.profit$product ==
"fuelwood")

  nrotations = as.integer(nyears/curr$age)

  nseq = as.integer(nrotations/maxrp)

  total.profit = 0.0

  total.discounted.low = 0.0

  total.discounted.med = 0.0

  total.discounted.high = 0.0

    for (j in 1:maxrp) {

        curr = subset(scen.profit, scen.profit$ID==id & scen.profit$rp == j)

        curr.max = which.max(curr$profit)

        max.product = curr[curr.max,]$product

       tmp = subset(scen.profit, scen.profit$ID==id & scen.profit$rp==j & scen.profit$product
== max.product)

              for (k in 1:nseq) {

                    time = ifelse(k==1,j*tmp$age, tmp$age*(j+((k-1)*4)))

                    discount.low = 1/((1+discount.rate.low)^time)

                    discount.med = 1/((1+discount.rate.med)^time)

                    discount.high = 1/((1+discount.rate.high)^time)

                    total.profit = total.profit + tmp$profit
```

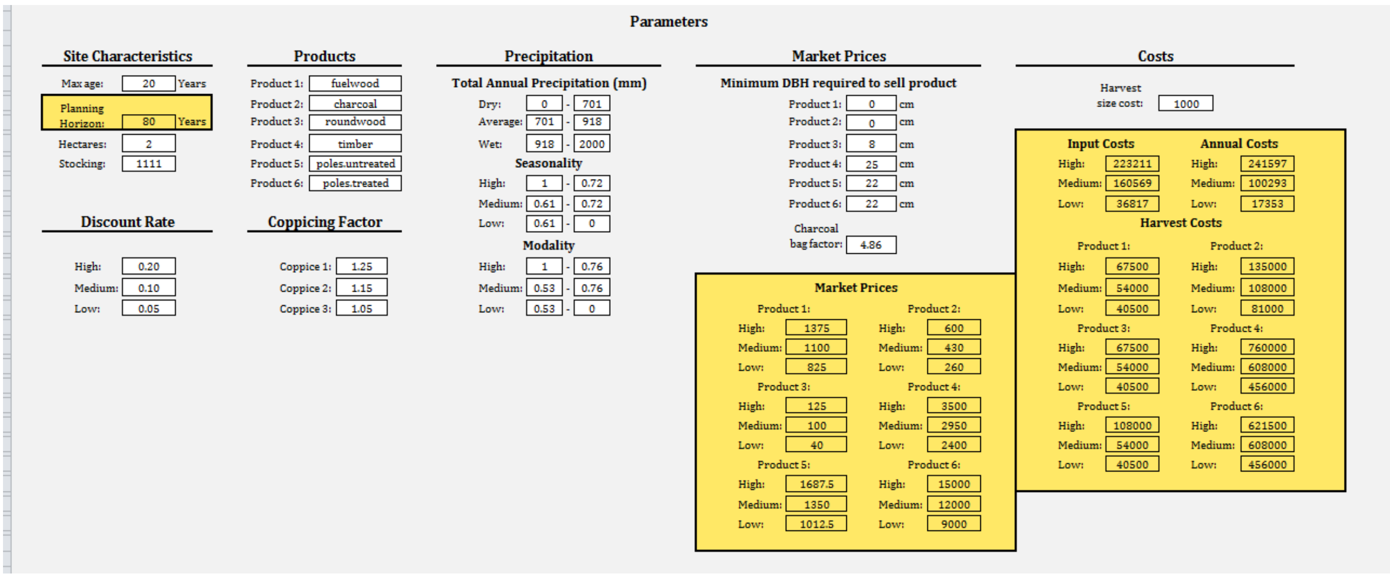
```
                total.discounted.low = total.discounted.low + tmp$profit * discount.low
                total.discounted.med = total.discounted.med + tmp$profit * discount.med
              total.discounted.high = total.discounted.high + tmp$profit * discount.high
            }
          for (m in (nseq*maxrp+1):nrotations) {
                time = ifelse(m==(nseq*4+j),m*tmp$age,0)
                discount.low = 1/((1+discount.rate.low)^time)*time/(m*tmp$age)
                discount.med = 1/((1+discount.rate.med)^time)*time/(m*tmp$age)
                discount.high = 1/((1+discount.rate.high)^time)*time/(m*tmp$age)
                total.profit = total.profit + tmp$profit * time/(m*tmp$age)
                total.discounted.low = total.discounted.low + tmp$profit * discount.low
                total.discounted.med = total.discounted.med + tmp$profit * discount.med
              total.discounted.high = total.discounted.high + tmp$profit * discount.high
          }
      result[i,j+(ncol(result)-4)] = max.product
      }
  result[i,"ID"] = id
  result[i,"total_profit"] = total.profit
  result[i,"discounted_profit_low"] = total.discounted.low
  result[i,"discounted_profit_med"] = total.discounted.med
  result[i,"discounted_profit_high"] = total.discounted.high
}
final.result = merge(result, dbh.array[,c("age","epg.scen","ID")], by.x=c("ID"))
write.csv(final.result, "final.result.LC.LR.csv")

################################################
######### RESULTS LOW DISCOUNT #################
################################################
LCLRLD = aggregate(final.result$discounted_profit_low, by=list(final.result$epg.scen), max)
colnames(LCLRLD) = c("epg.scen","discounted_profit_low")
temp = merge(LCLRLD, final.result, by=c("discounted_profit_low"))
lowcost.lowrev.lowdiscount.optimal.harvest= subset(temp, temp$epg.scen.x==temp$epg.scen.y)
#write.csv(lowcost.lowrev.lowdiscount.optimal.harvest,  "lowcost.lowrev.lowdiscount.opti-
mal.harvest.csv")

################################################
######### RESULTS MED DISCOUNT #################
################################################
```

```
LCLRMD = aggregate(final.result$discounted_profit_med, by=list(final.result$epg.scen), max)

colnames(LCLRMD) = c("epg.scen","discounted_profit_med")

temp = merge(LCLRMD, final.result, by=c("discounted_profit_med"))

lowcost.lowrev.meddiscount.optimal.harvest = subset(temp, temp$epg.scen.x==temp$epg.scen.y)

write.csv(lowcost.lowrev.meddiscount.optimal.harvest, "lowcost.lowrev.meddiscount.optimal.harvest.csv")


################################################

######### RESULTS HIGH DISCOUNT ################

################################################

LCLRHD = aggregate(final.result$discounted_profit_high, by=list(final.result$epg.scen), max)

colnames(LCLRHD) = c("epg.scen","discounted_profit_high")

temp = merge(LCLRHD, final.result, by=c("discounted_profit_high"))

lowcost.lowrev.highdiscount.optimal.harvest = subset(temp, temp$epg.scen.x==temp$epg.scen.y)

#write.csv(lowcost.lowrev.highdiscount.optimal.harvest, "lowcost.lowrev.highdiscount.optimal.harvest.csv")


---------Repeat for remaining cost/revenue scenarios-------------
```

Appendix G: GaPP Tool Interface



Scenario selection screen in GaPP Tool Interface



Parameter selection GaPP Tool interface

Kenya Planit

Masters Final Report 2013

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