Is control through utilization a cost effective *Prosopis juliflora* management strategy?

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Abstract

The invasive tree *Prosopis juliflora* is known to cause negative impacts on invaded ranges. High *P. juliflora* eradication costs have swayed developing countries to follow a new and less expensive approach known as *control through utilization*. However, the net benefits of this new approach have not been thoroughly evaluated. Our objective was to assess the economic feasibility of selected *P. juliflora* eradication and utilization approaches that are currently practiced in one of the severely affected developing countries, Ethiopia. The selected approaches include converting *P. juliflora* infested lands into irrigated farms (conversion), charcoal production, and seed flour production. We estimate the costs and revenues of the selected *P.*

juliflora eradication and utilization approaches by interviewing 19 enterprise owners. We assess the economic feasibility of the enterprises by performing enterprise, break-even, investment, sensitivity, and risk analyses. Our results show that conversion to irrigated cotton is economically profitable, with Net Present Value (NPV) of 5,234 US\$/ ha over 10 years and an interest rate of 10% per year. Conversion greatly reduces the spread of *P. juliflora* on farmlands. Managing *P. juliflora* infested lands for charcoal production with a four-year harvest cycle is profitable, with NPV of 805 US\$/ ha. However, the production process needs vigilant regulation to protect native plants from exploitation and caution should be taken to prevent charcoal production sites from becoming potential seed sources. Though flour from *P. juliflora* pods can reduce invasions by destroying viable seeds, flour enterprises in Ethiopia are unprofitable. Conversion and charcoal production can be undertaken with small investment costs, while flour production requires high investment costs. Introducing new changes in the production and management steps of *P. juliflora* flour might be considered to make the enterprise profitable. Our study shows that *control through utilization* may be a viable *P. juliflora* management strategy under the right environmental setting.

Key words: animal feed, charcoal, control through utilization, irrigated farming, *P. juliflora*, profitability

1. Introduction

Prosopis juliflora is a fast growing tree that is native to frost free tropical regions of Peru and/or Central America (Burkart, 1976; Pasiecznik et al., 2001, Alban et al., 2002). In the 1970's it was introduced to East African countries through collaborative efforts of governments and international development organizations (Coppock, 2005). It was primarily introduced to rehabilitate degraded soils, to supply firewood and fodder and to combat desertification (Zollner, 1986; Shackleton et al., 2014). However, the species rapidly naturalized and expanded into new locations, where it was neither anticipated nor desired. *Prosopis* taxa, which comprise 44 species have spread into a large number of semi-arid and arid countries worldwide including India, Pakistan, Iraq, Kenya, South Africa, Australia, Dominican Republic, Mexico, Venezuela and the United States (Burkart, 1976; Shackleton et al., 2014). The invasive *P. juliflora* plant widely occurs in Ethiopia's Afar region where it currently occupies an estimated 360,500 ha of arid and semi-arid lands (Wakie et al., 2014).

The purpose of this study is to compare management strategies that aim to eradicate the species with those that try to utilize it. Since *P. juliflora* is one of the controversial plants that possess both beneficial and harmful traits, eradication might not be the best option. For example, Kenyan women benefited from easily available *P. juliflora* firewood, while Kenyan herders and farmers often experience the adverse impacts of *P. juliflora* on native plants and associated control costs (Mwangi and Swallow, 2008). The species has several documented uses, both in its native and introduced ranges. In its native range, the species is exploited for human food, animal feed, medicine, timber, honey and energy products (Pasiecznik et al., 2001; Felker, 2005). In India, the species is grown for firewood, charcoal, and generating electric power (Gupta, 1985; Sato, 2013). The species has potential as an agroforestry plant (Singh, 1995), and as a biotic

carbon pool (Geeising et al., 2000). In Ethiopia, *P. juliflora* is widely used for animal feed, firewood and charcoal production purposes (Admasu, 2008), but it is unexploited for human food, honey, timber, and electric power production purposes.

Despite its beneficial uses, the species poses a threat to native ecosystems, pastoralism and dry-land farming. The negative impacts of *P. juliflora* include loss of biodiversity (Schachtschneider and February, 2013), reduction of water resources (Gorges and Willgen, 2004; Scott et al., 2006), degradation and loss of rangelands and farmlands (Zimmerman et al., 2006), mortality and decreased livestock health due to high intake of toxic seed pods¹ (Tabosa, 2006; Admasu, 2008), and high clearing costs on farmlands and rangelands (McConnachie et al., 2012). Efforts to control *Prosopis* species around the world, particularly by mechanical and chemical means, have been expensive and ineffective (McConnachie et al., 2012; CSIRO, 2013; Sato, 2013). As a result strategies that aim to minimize costs and maximize economic benefits are being sought in several developing countries. For instance, a strategy of managed utilization, controlling through utilization and eradication by utilization, has been advocated in Ethiopia, Nigeria, and Kenya (Borokini and Babalola, 2012; Tessema, 2012; Wakie et al., 2012). These utilization schemes are promoted in developing countries because they create new income opportunities for the affected communities, while positively contributing towards the control and management of the invasive species. Biological and mechanical controlling approaches, which incur higher costs, are the least preferred options in most developing countries (Shackleton et al., 2014).

While much of the management emphasis on invasive species might be oriented towards eradication, people in developing countries have generated new incomes by exploiting the

¹ Animals feed on *P. juliflora* seed pods especially in drought conditions. However, its leaves are not palatable. In Ethiopia, animal feed products containing up to 20% *P. juliflora* flour are considered safe.

invasive *P. juliflora* trees. Rural households in developing countries have increased their average income by growing and managing *P. juliflora* trees for wood energy (e.g., Sato, 2013). Common *P. juliflora* control and management practices include burning, digging out stumps, thinning, pruning, and harvesting (Pasicznik et al., 2001; Njoroge et al., 2012; Wakie et al., 2015). The decision to eradicate *P. juliflora* or to manage it for different income generating purposes may depend on its location. For instance, near water sources where irrigation is possible, farmers choose growing agricultural crops over *P. juliflora*. Moreover, in marginal lands where water-intensive agriculture is not possible, farmers choose growing *P. juliflora* over agricultural crops (Sato, 2013).

Agro-pastoralists in eastern Ethiopia use *P. juliflora* firewood in their households (Haji and Mohammed, 2013). Managing *P. juliflora* trees for firewood production can be profitable. For instance, in India, a *P. juliflora* fuel-wood plantation, that was managed with a six-year harvest cycle was found to be profitable with a Net Present Value (NPV)= 4,040 Rupees/ ha (Gupta, 1985). In its native range, growing *Prosopis* for timber production with a thirty-year harvest cycle, was found to be profitable (net profit = 9,777 US\$/ ha; Felker, 1999); however, the practice of harvesting trees at a younger age has restricted *P. juliflora* timber production in Ethiopia. In Afar (Ethiopia), transporting charcoal is cheaper than transporting fuel-wood logs. Thus, more people in Afar are involved in *P. juliflora* charcoal business than *P. juliflora* firewood business.

Existing *P. juliflora* eradication and utilization practices in Ethiopia include conversion of *P. juliflora* invaded lands into irrigated agriculture, charcoal production, and flour production (Admasu, 2008, Wakie et al., 2012). Non-governmental organizations (NGOs) working in Afar have in the past formed cooperatives that produced and sold *P. juliflora* charcoal and flour

produced from its seed pods (Admasu, 2008). *Prosopis juliflora* charcoal, grown and produced in Afar, is currently distributed and sold in major Ethiopian cities including Addis Ababa and Mekelle (Bekele and Girmay, 2013). Flour, which is used as animal feed, is produced by crushing and milling *P. juliflora* seed pods.

Though several *P. juliflora* utilization and eradication methods are practiced in Ethiopia, we could not find any published studies that analyzed and compared their economic profitability. Identifying and implementing economically feasible *P. juliflora* management strategies is essential for developing countries, as biological and mechanical approaches for controlling its spread are expensive and largely inaccessible. The objectives of our study are to: a) identify *P. juliflora* eradication and utilization approaches used in Ethiopia, b) describe the production and management steps of the identified practices, and estimate all costs and revenues; and c) assess the economic viability of these *P. juliflora* eradication and utilization approaches through income, income sensitivity and risk.

2. Methods

2.1 Study Site

The study was conducted in Amibara and Gewane *woredas* (counties) of southern Afar, north-eastern Ethiopia (Figure 1). The majority of the Afar people are pastoralists and their main livelihood is based on rearing livestock. The region's agro-ecology is semi-arid in the south, arid in the center, and desert in the north and north-east. Elevation in Afar ranges from 125m below sea level to 2,870m above sea level. The mean annual precipitation of the study site is 580mm, while the mean annual temperature is 26.6°C. Afar faces recurrent natural drought and intermittent flooding from the Awash River. Recent policies of the central government (e.g., for

agriculture-led industrialization, growth and transformation) encourages the Afar people to minimize their mobility and practice farming. Several government and privately owned large-scale farms are present in the study site. Farming is mostly conducted by irrigating the fields using water from the Awash River. Rain-fed farming is not practiced in the study site due to the lack of precipitation and high rate of evapotranspiration. The region contains the largest area of *P. juliflora* infestation in Ethiopia. In Afar, *P. juliflora* has extensively invaded the flat lands along the Awash River and the Alledeghie Plain, an extensive grassland area located in Amibara *woreda*, northern Afar and the Somali region (Figure 1).

2.2 Data Collection

Based on previous *P. juliflora* research findings, we identified one eradication and three utilization strategies practiced in the study site (Wakie et al., 2012; Wakie et al., 2015). The primary eradication practice identified was converting *P. juliflora* infested lands into irrigated farms (irrigated farm enterprise), while the three utilization practices identified were charcoal production (charcoal enterprise), *P. juliflora* seed pod flour production (flour enterprise), and firewood production. Afar communities regularly use *P. juliflora* in their households for firewood; but, we found very few people who sell it as an income source. Since *P. juliflora* firewood production did not exist as an enterprise in our study site, we did not include it in our economic analysis. Our study included 19 enterprises: one cooperative-owned flour enterprise², eight farms, and 10 charcoal enterprises. Cotton and sugarcane are the two principal agricultural crops grown in the study site. We collected data only on small-scale cotton farm enterprises (farm size ranging from one to 10 ha). Most small-scale farmers in Afar clear *P. juliflora* infested

² We found only one cooperatively owned flour enterprise in the region. We deemed it representative of this new enterprise type after interviewing the cooperative's secretary and accessing their original financial documents.

lands using manual labor, and grow agricultural crops on cleared lands. But, the large-scale farmers, who have sufficient financial capital, indiscriminately clear both the native and invasive *P. juliflora* trees using heavy machinery. For this reason, our study focused on the small-scale farmers because they see *P. juliflora* both as a challenge and as an opportunity.

We collected data from the field in April and May 2014 by obtaining the names and addresses of the 19 enterprise owners from the *kebele* representatives. According to the regions' government structure, *kebele* constitutes the lowest level legal administrative body. We collected data on the production and management steps required to produce three products, i.e., cotton, *Prosopis* charcoal, and *Prosopis* flour by interviewing the 19 enterprise owners (see Appendix I for interview questions). Additionally, we collected data on costs (i.e., investment, production, and labor), yields, prices and revenues for all three products from the 19 interviewees. Two of the authors, and one hired multi-lingual Ethiopian professional conducted the interviews. The study design was pre-approved by the Social, Behavioral, and Education Research Institutional Review Board at Colorado State University (Protocol # 14-5049H).

2.3 Data Analysis

Based on the survey results, we estimated costs and revenues for the three enterprise types, prepared enterprise budgets, and performed enterprise, investment, break-even, sensitivity, and risk analyses. Large initial costs occurring at the establishment of an enterprise were amortized (Sharp et al., 2002). For the purpose of estimating costs of farm and charcoal enterprises, we assumed the lifetime of machineries and equipment to be 10 years, and their salvage values to be 10% of their purchase prices. For the more expensive flour enterprise, we assumed the lifetime of machineries to be 20 years, and the salvage value to be 10% of purchase price. The lifetime of

machinery and equipment, and their salvage values used in our analysis were confirmed by interviewees to be representative and reasonable. We calculated machinery and equipment depreciation for all enterprises using the straight line method. We used 10% interest rates in all of our calculations as this rate was used by Ethiopian banks in most long-term loans. Annual investment cost was obtained by adding annual depreciation and annual interest cost. The annual interest cost (I) was calculated using the equation:

$$I = [(Purchase\ price + Salvage\ value) / 2] * i; \quad \text{where } i = 10\% \quad (1)$$

We calculated gross margins by subtracting operating costs from revenues. Break-even prices were obtained by dividing total costs with expected yields, while break-even yields were obtained by dividing total costs with output prices (Kay et al., 2012). We assessed the profitability of enterprises by projecting cash flows for 10 years, and computing Net Present Values (NPV; Brown and Kwansa, 1999; Connor, 2006; Stille et al., 2011). In NPV analysis, all future costs and benefits are discounted to the present value, permitting easy comparisons of policy or management alternatives (Boardman et al., 2010). Projects with positive NPVs are profitable, while projects with negative NPVs are unprofitable. For a given discount rate (r), time in years (t), project life in years (n), total revenue per year (Rt) and total expenses per year (Et), the total Net Present Value (US\$/ ha) over the life of an investment (T) is calculated using the following equation:

$$NPV_T = \sum_{t=0}^n (Rt - Et) \cdot (1+r)^{-t} \quad (2)$$

We performed sensitivity tests for all enterprise types by making $\pm 20\%$ changes in investment costs, gross revenues (prices and yields), and interest rates. The sensitivity tests were conducted to investigate the relative contribution of each economic variable to the profit, and to assess the vulnerability of each enterprise to changes in input costs. Sensitivity tests show how the profit changes *ceteris paribus* of the variables' changes. We used tornado diagrams (tornado charts) to visualize sensitivity test results.

We analyzed and ranked the outcomes when including risk for the three enterprise types using Simetar© software (Richardson et al., 2008). We selected prices, yields, fixed costs, and operating costs as stochastic variables. We estimated the means and standard deviations of the selected variables using our data and secondary sources (Table 1). We calculated gross margin values, for all enterprise types, by simulating the stochastic variables one-hundred times (normal distributions with means and standard deviations). We generated cumulative distribution functions (CDFs) of the gross margin values, and subjected the CDFs to first- (FSD) and second- (SDD) order Stochastic Dominance tests, which are concepts used for ranking risky alternatives (Hadar and Russell, 1969). The decision rule specifies that, for non-crossing CDFs, one distribution dominates another for any risk preference by a decision maker, whether they be risk averse, risk neutral or risk loving. If CDFs intersect, then second-order stochastic dominance can be used to rank distributions, with the assumption that the decision maker is risk averse (Hadar and Russell, 1969; Richardson, 2014). Distributions cannot always be ranked, but when they can, Stochastic Dominance is a valuable tool because it ranks different options for risk and returns without the need to measure individual risk preferences of the decision makers that will be considering these production alternatives. When distributions cannot be ranked with Stochastic Dominance, they can be ranked with other methods that require more information about the

unique risk preferences of the decision makers. We describe in the results where first or second degree stochastic dominance are effective. In the case of FSD, we are able to state that farmers that consider risk and income will prefer one of the three management options to all others. In the case of SDD, we can state that anyone that is risk averse would prefer one of the options to the other two. Since risk and resilience are of paramount concern in developing regions, this information helps assure that a risky, but profitable management option is not being recommended without stating so.

3. Results

3.1 Conversion

Conversion is usually practiced on flat lands near the Awash River where the land is suitable for irrigated farming. *Prosopis juliflora* infested lands are converted into irrigated cotton, onion, and corn farms. The production and management steps undertaken for the widely grown cotton crop include clearing invaded lands, digging out stumps and roots, burning (charcoal making is optional), land preparation (ploughing, grading, leveling and ridging), seed sowing, weeding, watering, applying pesticides, guarding, picking cotton, packaging, storing, and transporting the product to Awash market (interview questions 1- 4 & 6 -11, Appendix I). New *P. juliflora* seedlings that regenerate on cleared lands are regarded as normal weeds and controlled by regular land preparation and weeding practices. Cotton is grown on annual basis over a 10-month period. After cotton is harvested the remaining stalk is left for the Afar livestock to freely browse. Small-scale farmers get the land preparation work done through contractual agreements with large-scale farmers in the study site. The average yield of cotton in the study site was 36

quintal/ ha, and one quintal of raw cotton was sold for 61.86 US\$ (1,200 Birr³) at the Awash market (interview question 11; Appendix I). Cotton is grown by removing *P. juliflora* and/or the native vegetation. Farmers reported that growing cotton on *P. juliflora* cleared lands can increase its yield by 27% (10 quintal/ ha/ year) in the first five years (interview question 3; Appendix I).

Investment cost needed to grow cotton on one ha of *P. juliflora* cleared land is 53 US\$ (Table 1). Growing cotton with own machinery and at a larger scale (100 ha of land on average) requires large initial investment, worth 136,521 US\$. Detailed economic analysis is done only for small-scale farms, which were the focus of this study. The gross margin for converting *P. juliflora* infested land into irrigated cotton farm in southern Afar was found to be 508 US\$ (Table 1). Enterprise budgets and investment costs for all the studied *P. juliflora* eradication and utilization options are shown in Appendix II. Our investment analysis, based on 10 years of projected returns and expenses, showed that the investment can be profitable with a Net Present Value (NPV) of 5,234 US\$/ ha (Table 1). The NPV values for conversion remained above zero throughout the ten projected years (Figure 2). The break-even price was 48 US\$/ quintal, while the break-even yield was 28 quintal/ ha. Sensitivity tests using a tornado diagram showed that conversion is sensitive to gross revenue, slightly sensitive to interest rate, and less sensitive to initial investment (Figure 3). The risk analyses shows that conversion has first-order stochastic dominance (preferred by all risk preference types) over flour, while charcoal has second-order stochastic dominance (preferred by all risk averse decision makers) over conversion (Figure 4).

3.2 Prosopis Charcoal

³ Birr is the unit of currency used in Ethiopia. In April and May 2014, 1US\$ was equivalent to 19.4 Ethiopian Birr.

Prosopis juliflora infested lands that are currently unsuitable for conversion (e.g., due to inaccessibility to irrigated water or due to high flood risks) are typically exploited for charcoal. In the study site, most of the charcoal is also produced from *P. juliflora* trees growing in communal lands. Charcoal is produced near tree harvesting sites using the earth-mound-kiln method. Charcoal producers (usually Afar men or women with traditional land-use rights) produce charcoal by hiring immigrant labor⁴. The charcoal production and management steps include felling trees, debranching, cutting wood into smaller pieces (the remaining leaves and branches are usually burned), drying wood, gathering dried wood in one location and piling it, covering piled wood with soil and tree leaves, lighting the piled wood and closely monitoring the carbonization process (interview questions 1, 2 & 4; Appendix I). When carbonization is complete, the produced charcoal is cooled, packed using polypropylene bags, and temporarily stored at the production site (interview question 4; Appendix I). The average charcoal yield obtained in one production cycle is 150 bags. On average, one bag of *P. juliflora* charcoal weighs 25kg. All charcoal making steps, from harvesting to packaging, are completed within one month. Charcoal distributors, who also absorb the loading and unloading fees, drive to the production site and buy charcoal at an average price of 2.58 US\$/ bag. Charcoal producers reported that, on average, one hectare of *P. juliflora* infested land can yield 450 bags of charcoal every four years (interview question 4; Appendix I).

We performed the economic analysis using this average yield (i.e., 450 bags of charcoal/ ha), and assessed the sensitivity of the business to $\pm 20\%$ changes in charcoal gross revenue, investment cost, and interest rate. The investment cost needed for a charcoal enterprise in southern Afar was 127 US\$ (Table 1). Harvesting occurs on mature *P. juliflora* trees that are

⁴ Ethiopians from the densely populated Southern Nations, Nationalities, and Peoples' region (SNNP), migrate to sparsely populated areas like Afar to get temporary employment.

freely available. Therefore, we assumed the tree tending costs that occur prior to harvesting trees are zero. Replanting is also not needed as *P. juliflora* trees coppice soon after harvest. However, the coppice stand has to be thinned and pruned to produce sustainable yield. The gross margin of a *P. juliflora* stand that is managed for charcoal production with a four-year harvest cycle was 571 US\$ (Table 1). Our investment analysis showed that a *P. juliflora* charcoal enterprise in southern Afar is profitable with NPV of 805 US\$/ ha (n=10; Table 1). The NPVs in non-harvest years remained below zero (Figure 2). The break-even price was 1.34 US\$/ bag of charcoal, while the break-even yield was 236 bags of charcoal/ ha. The sensitivity tests using a tornado diagram showed that the charcoal enterprise is sensitive to gross revenue, slightly sensitive to interest rate, and less sensitive to initial investment (Figure 3). The charcoal enterprise emerged as the most preferred alternative when risk is considered, with first-order stochastic dominance over flour, and second-order stochastic dominance over conversion (Figure 4).

3.3 *Prosopis* Flour

Flour made from *P. juliflora* pods is used to feed cattle (both beef and dairy), poultry, sheep, goats, and camels. In the study region, *P. juliflora* produces pods twice a year. The main pod production and harvesting season (locally referred as *hagai*) occurs in May and June, while the second harvesting season (locally referred as *gilal*) occurs in October. The production and management steps involved in *P. juliflora* flour production include purchasing pods, drying pods, crushing pods (using mortar and pestles), and milling crushed pods using electric mills (interview question 4; Appendix I). The produced flour is packed using polypropylene bags and sold in the local market at a price of 0.1 US\$/ Kg (interview question 4, Appendix I). The investment costs needed to start a *P. juliflora* pod milling plant is 12,247 US\$ (Table 1).

Although the pods are purchased at lower prices, pod drying and crushing costs drive up the total flour production costs. We found that less than 50% of milling time is allocated for flouring *P. juliflora* pods. The mills do not process *P. juliflora* pods at full capacity because there is little demand for the product and pods are available only in certain seasons (*hagai* and *gilal*). The gross margin of the *P. juliflora* flour producing enterprise in southern Afar was -1,351 US\$ (Table 1). The investment is not profitable with NPV of -17,905 US\$ (n=10; Table 1). The break-even price was 0.47 US\$/ Kg of *P. juliflora* flour, while the break-even yield was 31,988 Kg of *P. juliflora* flour/ year. Increasing the production level alone did not make the enterprise profitable unless pod processing costs were highly reduced. Unlike conversion and charcoal, *P. juliflora* flour enterprise is sensitive to initial investment, slightly sensitive to gross revenue, and less sensitive to interest rate (Figure 3). Both charcoal and conversion have first-order stochastic dominance over flour, making it the most risky alternative (Figure 4).

4. Discussion

We compared the best *P. juliflora* eradication approach, conversion, with two utilization approaches, charcoal and flour. Converting *P. juliflora* infested sites into irrigated farms (conversion) resulted in the highest NPV. However, conversion can take place only on sites that are close to water sources, and sites that are edaphically and topographically suitable for irrigated farming. Government owned irrigation projects in Afar regularly maintain irrigation channels and dykes in the study site. But, broken and poorly maintained dykes may put some farm enterprises under high flood risk (personal observation). Furthermore, conversion was inferior to utilization for charcoal when risk is considered (Figure 4).

Prosopis juliflora is a nitrogen fixing plant that improves soil nutrient conditions (Tiedemann and Klemmedson, 1973; Felker, 2009; Ndhlovu et al., 2011) and known to ameliorate saline soils (Singh et al., 2011). Thus, the 27% additional yield reported by farmers who grow cotton on *P. juliflora* cleared lands (see section 3.1) may be due to the soil improving effects of the invasive *P. juliflora* plant. This new income, not used in our economic analysis, amounts to 139 US\$/ ha in a single year, and 695 US\$/ ha in five years (interest not included). Thus, farmers who participate in conversion can get additional revenue and a competitive advantage over non-participating farmers. We do not advocate for large-scale removal of forests and expansion of irrigated farms in the study site as this creates disturbance and facilitates the expansion of invasive plants (Wakie et al., 2015). However, our results show that converting infested sites into irrigated farms is an effective *P. juliflora* eradication option that is economically viable, where irrigation is feasible.

Our findings also show that managing *P. juliflora* infested sites for charcoal production purposes is economically feasible. Studies conducted in India also suggest that making charcoal from *P. juliflora* wood is profitable (Gupta, 1985; Stille et al., 2011). Charcoal yield can be considerably increased by introducing more efficient carbonization, torrefaction, and densification techniques (e.g., Adam, 2009; Chen et al., 2015). Improving charcoal yield can increase the gross margin of charcoal enterprises in Afar and make charcoal business even more profitable. However, we do not suggest planting new *P. juliflora* seedlings for charcoal making purposes as this may hasten the spread of *P. juliflora* in Afar. One of the challenges facing the charcoal enterprise is ensuring that charcoal is produced only from *P. juliflora* trees, not from the native plants⁵. Caution should also be taken to prevent charcoal forests from becoming potential

⁵ Current legislations indicate that producing charcoal from native trees is illegal in Ethiopia. Native trees are legally harvested for charcoal making in rare occasions (with special permits).

seed sources for *P. juliflora* spread. Charcoal policies (e.g., production, transportation) that seem to be lacking in the country (Bekele and Girmay, 2013) also need to be adjusted to account for the sustainable growth of the charcoal business in the region.

Making flour from *P. juliflora* pods can prevent new invasions by destroying viable seeds. However, the business was not economically viable under the current management practices implemented in southern Afar. The reasons include high initial investment costs, high pod processing costs (e.g., drying, crushing), and poor marketing practices. As a result, the major flour producing cooperative in southern Afar has shifted to milling food grains in place of *P. juliflora* pods. New ideas and practices should be introduced to make flour enterprises profitable. Reducing the initial investment cost, which was also the sensitive economic variable, may make the enterprise profitable. Investment costs can be reduced through owning and using flour mills in groups rather than individually. Other needed steps may include adoption of new marketing strategies (e.g. selling products at Awash and Addis Ababa markets), reducing pod drying and crushing costs, and changing the product type. In Kenya, for instance, the value of *P. juliflora* flour was highly improved by supplementing it with antiemetic medicines, converting it into feed blocks, and marketing the product as best animal feed that controls worms and increases livestock productivity (Syomiti et al., 2015). Flour enterprises in Ethiopia need support from research organizations, especially on nutritional values, chemical compositions, and toxicity levels of *P. juliflora* pods. Subsidizing flour producers should also be considered as contribution towards the control and eradication of this highly invasive plant.

Our profitability analyses clearly identified conversion as the best management alternative that gives high NPV. However, irrigation is possible only in limited locations and our risk analyses ranked charcoal production as the least risky alternative. An individual, who chooses

conversion, will likely make a profit in most production seasons; but, may occasionally lose or record a very high profit (Figure 4). Conversion is a suitable option for risk-taking individuals. Conversely, an individual, who engages in charcoal production, makes less profit than a cotton farmer. However, it is unlikely for charcoal producers in our study site to register a loss. Charcoal production is the most suitable alternative for risk-averse individuals (second-order Stochastic Dominance). Both of our NPV and risk analyses results ranked flour production as the least preferred alternative. However, appropriate policy and management interventions could make flour production profitable. Our overall economic analysis demonstrates that *control through utilization* is one of the effective and economically feasible *P. juliflora* management strategies currently accessible to developing countries. This novel approach has a potential to be used as alternative invasive species control strategy worldwide including United States. Finally, our results are based off of farmer interviews. These results need to be corroborated through research, especially in the long run.

5. Conclusions

The main *P. juliflora* eradication and utilization approaches practiced in Ethiopia include converting infested lands into irrigated farms, charcoal making, and production of flour from *P. juliflora* pods. We found converting infested lands into irrigated farms (conversion) to be the highly profitable *P. juliflora* eradication technique. In addition to providing economic benefits to farmers, conversion ensures total removal of *P. juliflora* from agricultural lands. However, lands allotted for conversion need to be accessible and suitable for irrigated farming. Conversion has high economic risk compared to charcoal production. Managing *P. juliflora* infested lands for charcoal production with a four-year harvest cycle is an economically viable utilization

technique. However, caution must be taken to stop the production sites from becoming potential *P. juliflora* seed sources, and to prevent native plants from illegal exploitation. Regional and national policies, particularly those that deal with *P. juliflora* charcoal production and transport, should be strengthened for the charcoal enterprise to grow. Producing *P. juliflora* flour prevents the expansion of new invasions by destroying viable seeds. However, *P. juliflora* flour producing enterprises are not economically profitable under the current management practices. Subsidies, enhanced products, and new marketing strategies may be considered to make flour enterprises profitable. Controlling the spread of the invasive *P. juliflora* through its utilization can be a cost-effective management strategy under the right environmental setting.

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Table 1. Initial investment costs, gross margins and Net Present Values (NPVs) for charcoal, irrigated farm (conversion) and flour enterprises in US\$.

Enterprise Type	Unit	Investment Cost	Gross Margin	Net Present Value (NPV)
Irrigated Farm	US\$/ ha / year	53	508	5,234
Charcoal	US\$/ ha/ year	127	571	805
Flour	US\$/ year	12,247	-1,351	-17,905

Table 2. Means and Standard Deviations (SDs) of prices, yields, operating costs, and fixed costs.

We used our data and information from secondary sources to estimate the values.

Stochastic Variables (Means, SDs)		Enterprise Types					
		Farm	Unit	Charcoal	Unit	Flour	Unit
Price	Mean	61.86	US\$/ Quintal	2.58	US\$/ Bag	0.10	US\$/ Kg
	SD	2.58	US\$/ Quintal	0.26	US\$/ Bag	0.03	US\$/ Kg
Yield	Mean	36.00	Quintal/ ha	450.00	Bag/ ha	7,000.00	Kg
	SD	10.00	Quintal/ ha	50.00	Bag/ ha	2,000.00	Kg
Operating Costs	Mean	1,460.82	US\$/ ha/ year	589.12	US\$/ ha/ year	2,072.94	US\$/ year
	SD	154.64	US\$/ ha/ year	51.55	US\$/ ha/ year	77.32	US\$/ year
Fixed Costs	Mean	7.63	US\$/ ha/ year	18.40	US\$/ ha/ year	1,224.74	US\$/ year
	SD	2.06	US\$/ ha/ year	2.32	US\$/ ha/ year	51.55	US\$/ year

Figure 1. Map of the study site. The study was conducted in Amibara and Gewane counties of the Afar administrative region (Ethiopia).

Figure 2. NPV trends of irrigated farm and charcoal enterprises over 10 years (US\$). NPVs for conversion were positive throughout the 10 years, while NPVs for charcoal showed positive values only in harvest years.

Figure 3. Sensitivity test. Sensitivity of irrigated farm, charcoal and flour enterprises to a $\pm 20\%$ change in gross income, interest rate, and initial investment costs.

Figure 4. Cumulative distribution functions (CDFs). CDFs of profits for irrigated farm, charcoal and flour enterprises in Afar.

Appendix I

Interview Questions

Location: _____ **Date:** _____

Primary Occupation: (Pastoralist, Agro-pastoralist, Farmer, Enterprise Owner)

Gender: (Male / Female)

1. What are the production and management steps required to clear *Prosopis*, and what time of year do they occur?

1.1 _____

1.2 _____

1.3 _____

1.4 _____

1.5 _____

2. What is the cost of each of these steps? (Define quantity of labor or other inputs used and prices of inputs).

No.	Production & Management step	Time of year	Units	Quantity	Unit Cost	Cost
2.1						
2.2						
2.3						
2.4						
2.5						
2.6						
2.7						

3. After removing *Prosopis* would your crop yield go up? (Yes/ No). If yes, indicate the quantity? Answer for all *Prosopis* control types and competing crops.

4. Do you generate income from *Prosopis* products? (Yes / No)

If yes, please answer 4.1 - 4.4; if no, proceed to 5. Answer yes if you harvest for your own use but do not sell any product.

- 4.1 What are the income generating *Prosopis* products that you produce? Give details about yields.

- 4.2 How much income do you get from each product (Birr/ha/yr)? Where is your market? What are the prices? Give details (If used at home, then specify what you could have sold the product for if you had not used it for home use)

4.3 What are the production and management steps required to harvest *Prosopis*?

No.	Production & Management step	Time of year	Units	Quantity	Unit Cost	Cost
4.31						
4.32						
4.33						
4.34						
4.35						
4.36						
4.37						
4.38						
4.39						

4.4 How do you store or process these products? (Answer for each product sold).

No.	Steps	Time of year	Units	Quantity	Unit Cost	Cost
4.41						
4.42						
4.43						
4.44						
4.45						
4.46						
4.47						
4.48						
4.49						

5. Is there any other use of *Prosopis* that you know about?

6. Would you be willing to convert the *Prosopis* infested land into other land use types? (Yes/ No) Please give details.

7. What are the pros and cons of converting *Prosopis* into other land use types?

8. What are the pros and cons of leaving *Prosopis* instead of clearing it?

9. What kind of enterprise do you own where the *Prosopis* is located?

10. What are the costs related to this enterprise? Use the following table to estimate costs.

No.	Steps	Time of year	Units	Quantity	Unit Cost	Cost
10.1						
10.2						
10.3						
10.4						
10.5						
10.6						
10.7						
10.8						

11. What are the incomes from this enterprise? Indicate product type, price and market location.

12. What are the main problems associated with this enterprise?

13. How much do you feel *Prosopis* reduces the profit of this enterprise (birr/hectare)? Please explain.

14. What solutions do you suggest, with respect to *Prosopis*, to make your enterprise more profitable?

15. Is there anything that we didn't ask regarding *Prosopis* that you would like to share?

Appendix II

Irrigated cotton enterprise investment cost for southern Afar (Ethiopia)

Interest rate 10%

Hectare 1

Farm tools	Unit price (Birr)	Quantity	Total purchase price (Birr)	Salvage value	Useful life (Years)	Depreciation	Interest	Annual cost (Birr)
Hand saw	400	1	400	40	10	36	22	58
Axe	200	1	200	20	10	18	11	29
Spade	90	1	90	9	10	8	5	13
Rake	90	1	90	9	10	8	5	13
Machete	90	1	90	9	10	8	5	13
File	60	1	60	6	10	5	3	9
Hoe	90	1	90	9	10	8	5	13
Total equipment investment	1020			102		92	56	148

Charcoal enterprise investment cost for southern Afar (Ethiopia)

Interest rate 10%

Equipment	Unit price (Birr)	Quantity	Total purchase price (Birr)	Salvage value	Useful life (Years)	Depreciation (Birr)	Interest (Birr)	Annual cost (Birr)
Hand saw	400	2	800	80	10	72	44	116
Axe	200	2	400	40	10	36	22	58
Spade	90	2	180	18	10	16	10	26
Rake	90	2	180	18	10	16	10	26
Machete	90	2	180	18	10	16	10	26
Shears	300	2	600	60	10	54	33	87
File	60	2	120	12	10	11	7	17
Total equipment investment						221	135	357

Prosopis flour producing plant investment cost for southern Afar (Ethiopia)

Interest rate 10%

Machine	Unit price (Birr)	Quantity	Total purchase price (Birr)	Salvage value	Useful life	Depreciation (Birr)	Interest (Birr)	Annual cost (Birr)
Mill (30 watt dynamo)	40000	1	40000	4000	20	1800	2200	4000
Transformer	100000	1	100000	10000	20	4500	5500	10000
Scale	15000	1	15000	1500	20	675	825	1500
Store (for drying pods and housing the mill)	80000	1	80000	8000	20	3600	4400	8000
Mortar	1000	2	2000	200	20	90	110	200
Pestle	300	2	600	60	20	27	33	60
Total machinery investment						10692	13068	23760

Irrigated cotton farm enterprise budget

Interest rate 10%

Hectare 1

Item	Units	Unit cost (Birr)	Quantity	Cost/ ha (Birr)
Operating costs				
Land preparation (contract)	ha	4400	1	4400
Seed	Kg	18	30	540
Cultivation	ha	800	3	2400
Water fees	ha	171	7	1197
Insecticide	ha	370	9	3330
Cotton bags (picking & compacting)	ha	82	21	1740
Storage	ha	504	1	504
Loading & unloading	Quintal	10	36	360
Transportation	Quintal	31	36	1116
Marketing costs	ha	300	1	300
Labor costs				
Land clearing (vegetation removal)	ha	5000	1	5000
Seed sowing	ha	800	1	800
Weeding	ha	250	6	1500
Watering	ha	240	7	1680
Insecticide application	ha	190	9	1700
Guarding	ha	500	1	500
Cotton picking and compacting	ha	3708	1	3708
Sub total				30775
Interest expense (10 months)				2565
Total operating costs				33340
Fixed costs				
Farm tools depreciation				92
Interest				56
Total fixed costs				148
Total costs				33487
Income				
Cotton (unprocessed)	Quintal	36	1200	43200
Total income				43200
Gross margin				9860
Profit (return to land and management)				9713

Charcoal enterprise budget (450 bags/ha)**Interest rate** 10%**Yield** 11.25 ton (450 bags each weighing 25kg) of charcoal with four years rotation

Item	Units	Unit cost (Birr)	Quantity	Cost per hectare (Birr)
Operating costs				
Labor costs				
Harvesting trees	ha	4000	1	4000
Cutting wood into smaller pieces	ha	2000	1	2000
Drying and piling wood	ha	900	1	900
Carbonization	ha	800	1	800
Cooling and packaging	ha	300	1	300
Packaging material	No.	7	450	3150
sub total				11150
Interest expense (3 months)				279
Total operating costs				11429
Fixed costs				
Equipment depreciation				221
Interest				135
Total fixed costs				357
Total costs				11785
Income				
Yield (bags of charcoal/ha)	No.	50	450	22500
Total Income				22500
Gross margin				11071
Profit (return to land and management)				10715

Prosopis flour enterprise budget for southern Afar (Ethiopia)**Interest rate** 10%

Item	Units	Unit cost (Birr)	Quantity	Cost (Birr)
Operating costs				
Purchasing pods (fresh weight)	Kg	0.5	20000	10000
Electric cost	month	700	6	4200
Packaging material	Kg	0.4	7000	2800
Marketing costs	Kg	0.05	7000	350
Machinery maintenance	No.	400	2	800
Labor costs	Kg			
Pod drying	Kg	0.3	20000	6000
Pod crushing	Kg	0.8	12000	9600
Packaging costs	Kg	0.05	7000	350
Mill operator	month	700	6	4200
Sub total				38300
Interest expense (6 months)				1915
Total operating costs				40215
Fixed costs				
Machinery depreciation				10692
Interest				13068
Total fixed costs				23760
Total costs				63975
Income				
Prosopis flour	Kg	2	7000	14000
Total income				14000
Gross margin				-26215
Profit (return to management)				-49975

Figure 1

Figure 2

Figure 3

Figure 4